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Growth and Decay of Light Measured Photographically From Flash-Discharge Tubes

By W. R. STAMP and R. P. COGHLAN

A method is described of plotting the light-time curves of flash-discharge tubes using purely photographic methods. Particular attention is given to tubes with flashes of the order of 5- to 10-μsec effective duration, but some results for longer duration tubes are included. The method has been employed to examine for a certain tube the influence on the effective photographic duration of the use of emulsions of widely different spectral sensitivity and speed. For the particular emulsions chosen the observed differences in effective flash duration are of small magnitude and insignificant in practice. Some observations are included of the influence of different capacities on total photographically effective light output (i.e. efficiency). The changes in duration and efficiency resulting from some different gas fillings in tubes which are otherwise identical are also recorded.

THE INCREASING USE of flash-discharge tubes as a light source for photography in almost every branch of research has led to a need for some knowledge of the shape and duration of the light-time curve of these tubes, particularly of the types having a very short flash of the order of microseconds.

Reports of previous work in which these tubes were used for various purposes have frequently included a statement of the effective duration of the flash without describing the means by which the figures were obtained. These were probably based upon the positional accuracy of measurement in the photograph of an object moving at known speed. This criterion has very little reference to the actual total time for which the light is emitted, which is a factor of major importance in other types of investigation.

It became clear, therefore, that it was necessary to devise a method for plotting the complete light-time curve, from which it might be possible, knowing the type of subject to be photographed, to deduce a figure for the effective time of flash in any given case, and thus to estimate in advance the type of lamp and conditions of discharge suitable for any proposed application. In addition, the ability to plot the light-time curve would enable investigations to be made of the effects of various modifications to the lamps, circuitry, or photographic technique, which might result in a reduction of the effective flash time.

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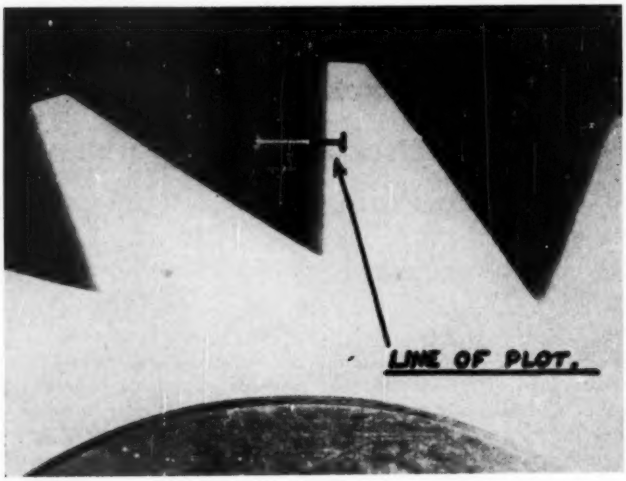

Fig. 1. Typical disk picture.

The Method

Previous work on this problem using a photocell/cathode-ray oscilloscope combination has been devoted to the longer duration discharges of the order of 10^{-4} sec. Even for these durations, this method is open to objection on the grounds that the spectral, and possibly even the time, response of a photocell is like to be totally different from those of photographic emulsions. Corrections cannot be applied, since the spectral quality of the light emitted probably varies during the period of the flash and the determination of such variations would be an extremely difficult task.

It was decided, therefore, that an extension of these methods to flashes of shorter duration was undesirable and that the use of a purely photographic technique would constitute the best procedure, since the question at issue is how photographic emulsions respond to flashtubes, and not how cathode ray oscilloscope/photocell combinations respond to them.

The most direct method of obtaining the required information would be to produce an image of a narrow slit, illuminated by the flash, moving rapidly across the surface of the photographic emulsion in a direction perpendicular to its length. The density profile of the resultant blur in the developed image could then be measured with a microdensitometer, and an evaluation of the light-time curve obtained by reference to the sensitometric curve of the emulsion exposed and developed under the same conditions.

Although possessing the merit of simplicity in principle, the practical achievement of a line image having a satisfactory ratio of width to speed of motion is somewhat difficult.

For this reason, the method actually adopted was that of photographing a rapidly moving edge, or boundary. This has an advantage inasmuch as it closely approaches the conditions found in many applications of flashtube photography. The sharpness of the edge, and hence the "time-resolution" for a given speed, is better than that of any practicable slit. It leads, however, to complications in the computation of

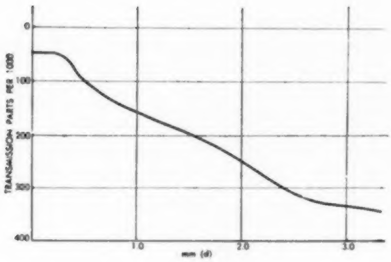

Figure 2

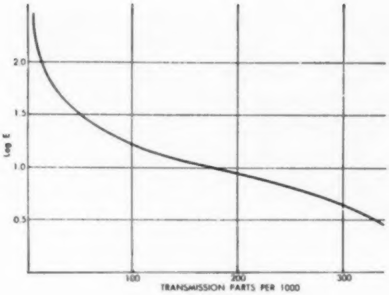

Figure 3

the final curve which add considerably to the labor involved, as will be seen.

The photography of the rapidly moving edge or boundary was performed in two alternative ways. In the first way, which was used in the initial stages of the work, a photograph was obtained with an ordinary camera of a rapidly rotating white disk having a number of slots or teeth cut out around its periphery. This disk was placed against a dead black background and illuminated by the light from a single flash of the flash-tube under examination. The type of photograph which resulted is shown in Fig. 1 in which the rapidly moving boundary between the black and white areas appears as a blur. In the second way, which was used at a later stage to simplify the operation of the apparatus, no camera was used at all, but a length of film was simply mounted as close as possible behind the spinning disk so that a shadow of the disk was cast on it by the light, again from a single flash of the tube. To ensure that this shadow was as sharp as possible the light from the tube was passed through a small aperture before it became incident on the disk and film. The shadowgraph which resulted was similar in appearance to Fig. 1 except that the blacks appeared white and vice versa. It may be mentioned here that the shadowgraph method tended to produce slightly shorter rise times in the final light-time curve than the camera method, which indicates a slightly higher time resolution.

Simultaneously with the production of each photograph or shadowgraph, a strip of the same batch of film was exposed in a tube sensitometer to light from the same flash after reflection from a matte white screen. The photograph or shadowgraph, together with its associated sensitometric strip, were then developed simultaneously, using developers and times of development which would be used in practice for flashtube photographs. By means of a microdensitometer the density (or transmission) profile of the blur in the disk picture along the line shown in Fig. 1 was plotted. The densities on the sensitometric strip were also measured with the same instrument.

The light-time curve of the flash was then derived as follows: From the experimental procedure described two curves were obtained.

(a) A plot of transmission T against distance d along the blur measured circumferentially in the disk picture.

(b) A sensitometric curve of transmission T against Relative Log Exposure.

The form of these curves obtained in a typical case is shown in Figs. 2 and 3.

Both the ordinates and abscissas of Fig. 2 are now transformed:

(c) Distance d is transformed to a time scale t by a linear relationship established from the measured speed of the disk and, in the cases in which the camera was used, the camera image reduction ratio.

(d) Transmission T is transformed to

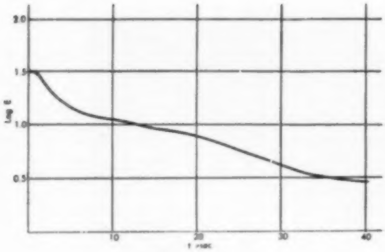

Figure 4

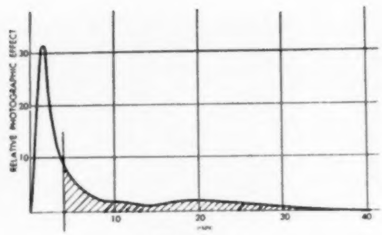

Figure 5

Relative Log E with the aid of the sensitometric curve.

The curve arrived at by applying these processes is shown in Fig. 4.

It is shown below that by differentiating this curve with respect to time, and then plotting the product of the slope and the corresponding exposure at any point against the corresponding time value, the final curve is obtained.

In Fig. 5, which represents the final curve, the line marked t corresponds to the position of the edge at the time t with white on the left and black on the right (since time and distance bear a linear relationship, the abscissas on this graph can be either, interchangeably). It is apparent that the density at this particular point on the blur will have been built up by the whole of the light following the instant when the edge reaches the point in question — i.e. by the area shown shaded. Exposure E is normally defined as Intensity $I \times$ time t, but since in the case of a flash, I is a function of t, E must be defined by the relation

$$E = \int_t^\infty f(t) \cdot dt \qquad (1)$$

This is for the leading edge of the disk in the case of a camera photograph. For the trailing edge in the same case the following relationship will hold:

$$E = \int_0^t f(t) \cdot dt \qquad (2)$$

In the case of a shadowgraph Eq. (1) applies to the trailing edge and Eq. (2) to the leading edge.

Thus from a plot of the density profile of the image of either the leading or trailing edge of the disk appropriately transformed to a curve of Exposure vs. Time, the flash-time curve may be obtained by differentiation. In practice the leading edge was used in the case of a photograph and the trailing edge in the case of a shadowgraph, since with these the major portion of the blur occurs at low densities which are more easily measured.

It was found that the curves of Exposure vs. Time which were obtained had very steep gradients and that in consequence the derivative was difficult to obtain in practice. To overcome this difficulty the differentiation was actually performed on a Log Exposure vs. Time curve such as that shown in Fig. 4, and use was then made of the relationship:

$$\frac{dE}{dt} = E \cdot \frac{d(\log E)}{dt} \qquad (3)$$

Apparatus

The Tube Sensitometer and the Rotating Disk. The tube sensitometer and its associated matte white, diffusely reflecting screen were disposed so that only light reflected from the screen could reach the film. The sensitometer itself, which is shown in Fig. 6, consists of six horizontal rows of tubes let into the surface of a brass plate. Each row consists of ten tubes 4 in. long, each tube having an entry aperture at one end, and an exit aperture at the other. All the

entry apertures lie in a common plane and all the exit apertures in a parallel plane. The film strip to be exposed is placed over one of the horizontal rows of exit apertures and, therefore, receives an exposure over ten different circular areas along its length. The intensity of each of these exposures is proportional to the area of the corresponding entry aperture, since the only source from which illumination is received is the diffusely reflecting screen. In a given row of tubes the areas of adjacent apertures differ by a factor of two, and the intensity range covered is therefore 1 to 512, or a log exposure range of 2.709. The circumferences of both entry and exit apertures is chamfered on the side facing the incident light so as to eliminate edge reflections, and the internal walls of the tubes are lined with dead black velvet, thus reducing reflections from these walls to the absolute minimum.

This type of sensitometer was used at first in order to eliminate any uncertainties in the spectral quality of the light reaching the film, which would be introduced by any lack of neutrality of the step wedge in a sensitometer of the intensity-modulated type (a time-scale sensitometer is, of course, not possible in this case). In the case of the tube sensitometer the spectral quality of the light reaching the film is controlled by the spectral reflectance of the matte white screen used in conjunction with it, which consisted of magnesium carbonate. This was as shown in Fig. 7, relative to magnesium oxide.

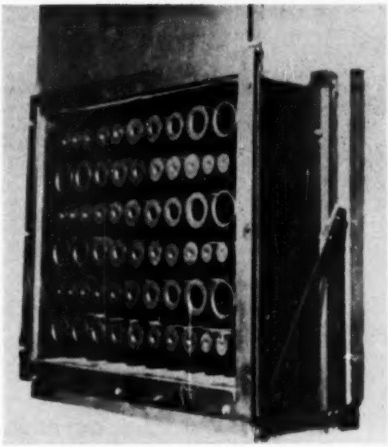

Fig. 6. Tube sensitometer.

Ideally it would have been desirable, in the case of camera photographs, for

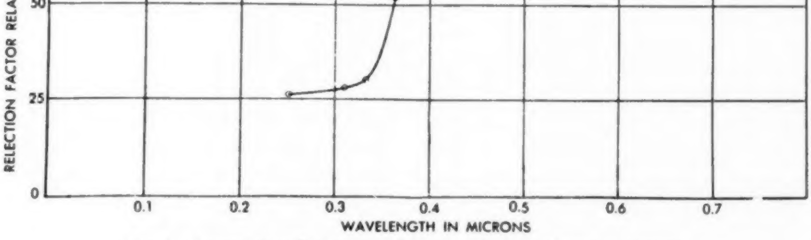

Fig. 7. Spectral reflectance of magnesium carbonate screen.

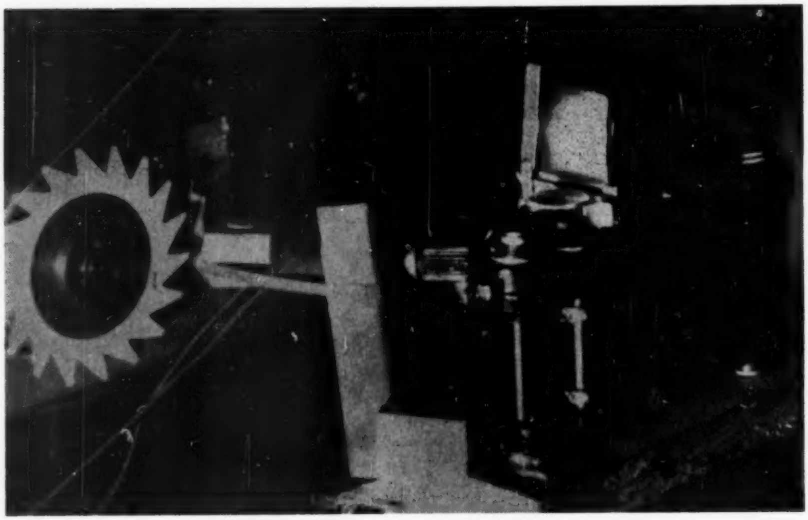

Fig. 8. Camera, disk and driving motor.

the reflecting surface of the disk to be coated with the same material as the screen so that the spectral reflectance of both would be exactly the same. It was found, however, that a satisfactorily clean edge could not be achieved on the disk when it was coated with this material. The disk, which was made from aluminum foil five thousandths of an inch thick coated on each side with white paper, was therefore smoked with magnesium oxide. The reflectance of magnesium oxide in the ultraviolet is considerably higher than that of the magnesium carbonate screen coating, as Fig. 7 shows, but it was considered that since this reflected ultraviolet would be largely absorbed by the glass of the camera lens, any difference remaining would be too small to cause significant variation of the contrast rendition of the film in the camera from that expressed by the characteristic curve derived from the sensitometric strip. This is the only condition which must be satisfied. Several light-time curves were obtained using this disk but it was found after a few runs that windage and centrifugal force removed the magnesium oxide.

An experiment was therefore made with another disk made from aluminum photographic foil, also five thousandths of an inch thick, but coated on one side only with a very thin pure white enamel overlaid with clear emulsion. It was found that with a given flashtube the curve obtained was sensibly the same as that given by the other disk, and so the enamelled disk was adopted and used for a considerable portion of the work. The form of this disk can be seen from Fig. 8 which shows the camera and disk with driving motor as a whole, and also from Fig. 1 which is a reproduction of a typical disk picture. The aluminum foil was 10 cm in diameter and it had 18 "teeth" of the form shown. One of the edges of the teeth was arranged to be radial. In the case of pictures taken with the camera this was made the leading edge since the blur appears ahead of the tooth. In the case of shadowgraphs the reverse holds, and for these the disk's direction of

rotation was such as to make it the trailing edge.

The foil was clamped between duralumin disks 6 cm in diameter to keep it flat and ensure truth when it was running. This was essential, as the depth of field of the camera was very small at the short distance at which it was used. Considerable care was taken over the accuracy of the boss and of the disk as a whole, and dynamic balancing was found to be unnecessary.

The face of the disk was 2 ft from the flashtube and for camera photographs the angle of incidence of the light was about 30°

At a later stage in the work, when the shadowgraph technique was employed, the tube sensitometer was replaced by an ordinary photographic step wedge when it had been proved that in combination with the shadowgraph it produced results consistent with those obtained previously.

The Driving Motor and Measurement of Speed. The disk was mounted on the shaft of a high-speed motor. The speed obtained ranged up to 27,000 rpm but, in the interests of the life of the motor and safety, it was generally run at approximately 20,000 rpm.

The speed of rotation at the instant of firing the flash was measured electrically. The method of picking up the signal from the motor is shown in Fig. 9. An armature was mounted on the end of the shaft opposite to the disk and arranged to run between the poles of a double-wound electromagnet. A small d-c polarising current was passed through one winding and the resultant a-c signal taken from the other. The resultant signal frequency, which was twice that of the motor speed, was compared with a variable known frequency from a beat-frequency oscillator. An independent approximate mechanical check of the speed was made by means of a tachometer to ensure that the setting was not being made on a multiple or submultiple

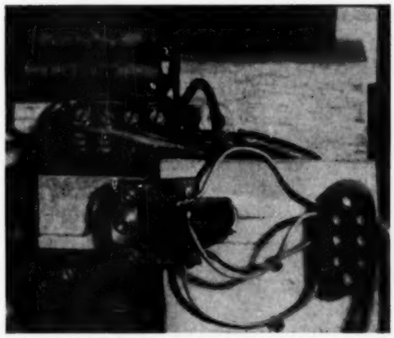

Fig. 9. Equipment for measuring speed of rotation.

of the correct frequency. The accuracy of the measurement was limited by the unsteadiness of the motor but readings to within 10 cycles/sec, or 2% approximately, were obtained.

The Camera. For the photographs the camera used was a 35mm reflex type with 7.5-cm lens operating at a reduction of 1.274 : 1. The aperture used ranged from $f/8$ to $f/22$ (as marked on the lens, i.e. not compensated for the extra extension), according to the speed of film used. The shutter was set to "time" and remotely operated by a solenoid. The exposure was chosen to result in a density of the black background at or near fog level. The speed of the image on the film plane was, for maximum speed of the motor, of the order of 100 m/sec.

Measurement with the Microdensitometer. The microdensitometer which was used is a nonrecording instrument using a barrier-layer cell and intended for use with spectrographic plates. To utilize the maximum range of the scale, it was adjusted to read zero density with the film base alone in the light path. This necessitated readjustment for each sample of film used. The effective width of the slit used was 0.025 mm and readings were normally taken at inter-

vals of 0.05mm in the case of short duration flashtubes. The effective length of the slit is about 1.5 mm and it was adjusted to be parallel to the blur at the point where the greatest change of density occurred. The slit is moved linearly while the blur is, of course, radial. The error involved over the very short distance traversed (3 mm) is negligible.

For convenience the transmission scale, and not the density scale, was used, as the reading is easier. In addition, the transmission measured was specular and not diffuse. Neither of these factors is of importance as the transmissions of the sensitometric strip were measured in exactly the same way.

The grain of the film caused some scatter of the points, particularly at low densities; these were smoothed on the graph before applying further transformations.

The Meaning of the Ordinate Scale

It will be noticed, e.g. in Figs. 5, 20 and 23 that the final ordinate scales are expressed as "relative photographic effect" and not "intensity." Strictly the photometric term luminous intensity has a purely visual connotation and is a measure of the luminous sensation produced in the eye by a source of radiant energy. Now the quantity which has been measured is the effect versus time on certain photographic materials, of radiation from some flashtube sources. It is therefore, much more appropriate that the term "photographic effect" should be applied to this quantity. Others may prefer the term "photographic intensity."

The ordinate scale is relative and not absolute since only relative log exposure values are known. For this reason the ordinate scales are not comparable from graph to graph except in the cases of the three curves on Fig. 20 and the two curves on Fig. 23.

The ordinate scales can be drawn so as to be comparable with each other for various lamps used under various conditions by reference to the relative total light outputs of the flashes. The relative light outputs can be obtained by measuring the maximum densities produced in the disk pictures and then referring these densities to the appropriate sensitometric curve and reading off the relative total exposures. Since these readings represent the relative integrals under the final curves the appropriate ordinate scale can be determined. This procedure was followed to obtain Figs. 20 and 23 which are given as examples.

If desired, it would be possible to determine the ordinate scales in terms of equivalent intensity of, say, tungsten light or mean noon sunlight, or other source, such as gas arc, more nearly equivalent in spectral characteristics to a flashtube. This could be done by reference to sensitometric curves of the emulsions obtained with these sources at constant known intensities and known exposure times. It is unlikely that sufficiently high intensities combined with sufficiently short exposure times could be produced with such sources as to reproduce the reciprocity failure conditions which occur with flashtubes. It is doubtful, however, whether this is necessary or, for practical purposes, desirable, since for photographic purposes the flashtube intensity scale could be equally well expressed in terms of equivalent intensity at normal exposure times. In this way allowance would automatically be given to the effect of reciprocity failure.

The character of the final photographic effect vs. time curve is controlled by the relationship between the spectral quality of the light reaching the film and the spectral sensitivity of that film. It is desirable that this should be so since it enables the effect of films of different spectral sensitivities upon the duration of the flash to be investigated. It should be noted, however, that the character of the final curve is entirely

independent of variations of gamma and shape of the sensitometric curve caused by any particular method of processing a given disk picture and its associated sensitometric strip. For this to be so, it is necessary only that both the picture and the strip should be given precisely the same processing of no matter what nature. Processing of any pair was in all cases by simultaneous brush development. This method gave the most consistent and reproducible results with comparatively simple apparatus. A comparison of two final curves, for the same tube and the same emulsion, obtained with markedly different development times and, therefore, different gammas, gave good agreement.

The Results Obtained (See Figs. 10–23)

The general characteristics of the flash from an S.F.7 or Arditron type of tube discharged under its maximum rated conditions of 2-μf capacity and 7.5 kv are exhibited by all the curves shown in Figs. 10 to 17. The position of the triggering pulse on the time scale is unknown. The main peak of the flash occurs about 2 to 3 μsec after the emission of light commences. This main flash is spent after about 8 μsec but is followed by a long "tail" at the comparatively low level of about 5% of the peak, which persists with appreciable magnitude up to about 30 μsec.

Detectable light output is present even after 50 μ sec but is too low to be shown easily on the graphs and much too low to be of practical significance.

Associated with this tail there is a secondary peak, small compared with the main peak, the relative height and time of occurrence of which vary somewhat from flash to flash. It usually appears at about 20 μsec. At this part of the curve the accuracy of the method is high and these variations in height and time do actually exist. Their cause is unknown.

Figures 10 to 15 show photographic effect — time curves obtained under

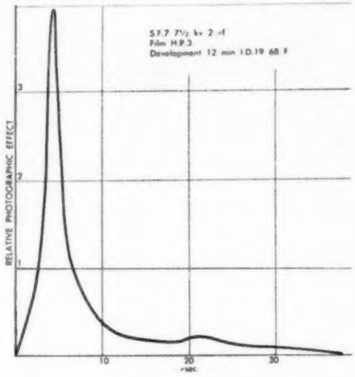

Figure 10

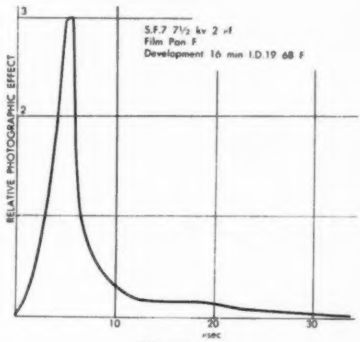

Figure 11

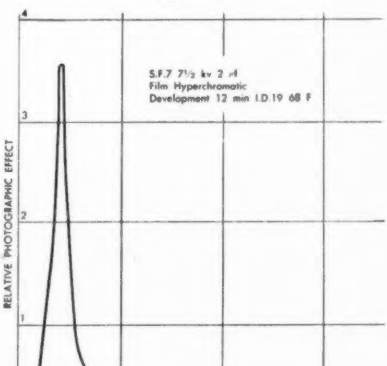

Figure 12

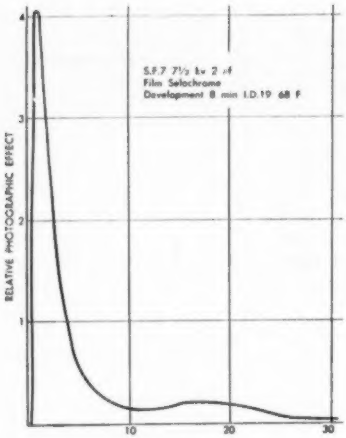

Figure 13

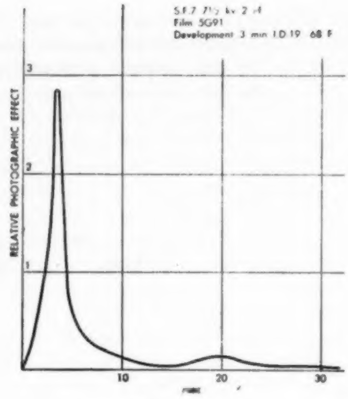

Figure 15

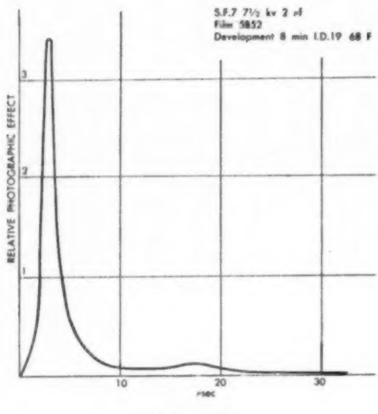

Figure 14

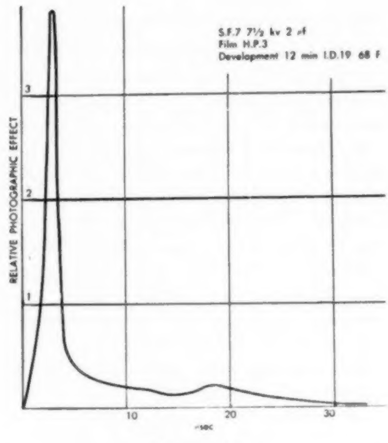

Figure 16

identical conditions for the flash of a Siemens S.F.7 tube, but recorded on several different emulsions. In all cases the capacity was 2 μf and the voltage 7.5 kv. These results were obtained with the earlier form of disk and in view of subsequent experience are regarded with some caution. This experience indicates that the rise time shown in the majority of cases is too long, and occasionally anomalous results, e.g. Fig. 13, were obtained.

From an examination of Figs. 10 to 15 there appears to be no significant advantage of effective flash duration with any of the six emulsions chosen which are of widely differing speeds and spectral sensitivity. In particular, there is no apparent advantage in any of the non-red-sensitive emulsions, a result which is in conflict with opinions expressed by others.

Figures 16 and 17 give a comparison between the Siemens S.F.7 and the

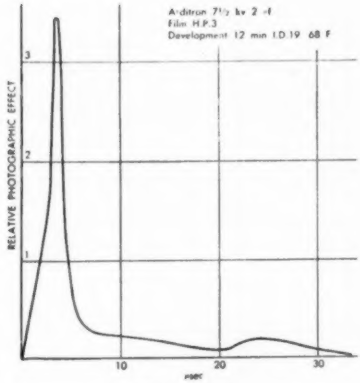

Figure 17

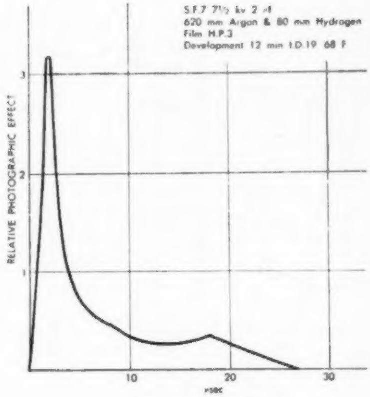

Figure 18

A.R.D. Arditron tubes under the same conditions on H.P.3 film. It is apparent that they have very similar photographic characteristics when flashed under these conditions, which represent their maximum rated power per flash. The total light outputs of these two tubes was found to be identical within experimental error. Their gas fillings were as follows:

S.F.7 — 590mm argon; 110mm nitrogen

Arditron — 613mm argon; 7mm nitrogen; 33mm hydrogen

Figures 18 and 19 show two S.F.7 tubes with nonstandard gas fillings. The relative light outputs of these tubes and of a standard S.F.7 were determined and the results, from which it appears that pure argon has a distinct advantage in this respect, were as follows:

Tube	*Gas Filling*	*Relative Light Output*
A	620 mm A 80 mm H_2	1.0
Standard S.F. 7	590 mm A 110 mm N_2	1.35
B	700 mm A	1.66

From the point of view of flash duration the standard S.F.7 and tube B are approximately the same. The effect of the hydrogen in tube A, however, appears to be to cause sudden complete

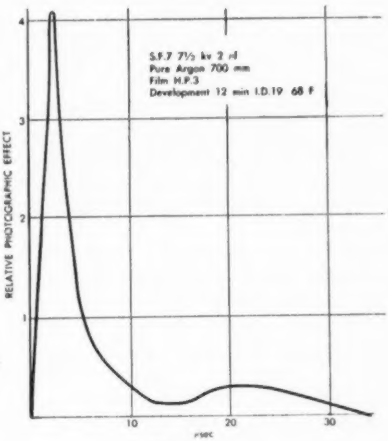

Figure 19

extinction at 25 to 30 μ sec, but the rate of decay over the earlier portion of the tail of the curve is less than with the other gas mixtures. It is of interest to note that this shorter tail was apparent from a visual comparison of the disk pictures. This more rapid cutoff is accompanied by about 30% decrease in photographic efficiency as compared with the standard S.F.7, whereas tube B has about 30% greater efficiency than the standard.

In examining the above curves it

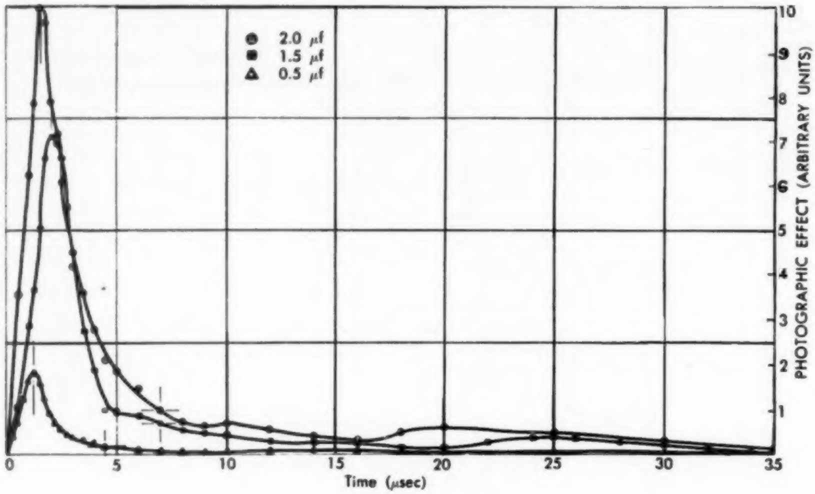

Figure 20

should be remembered that the peaks as plotted appear of different heights, and it is the ratio of this height to the height of the "tail" which is significant in considerations involving photographic duration.

Figure 20 shows the curves for a standard S.F.7 tube obtained by the discharge at 7.5 kv of capacities of 0.5, 1.5 and 2.0 μf. Within this figure the ordinates of the curves are comparable. There appears to be some decrease in the relative heights of the tail with decreasing capacity but there is no reduction in its overall duration. The secondary peak occurs later and is relatively somewhat smaller with smaller capacity. The duration of the main peak decreases considerably with capacity but not proportionately. The relative total light output in the three flashes was measured and is as follows:

	1st Flash	*2d Flash*	*3d Flash*
Capacity	0.5 μf	1.5 μf	2.0 μf
Relative total light output	1.0	5.4	8.1
Relative photographic efficiency	1.0	1.8	2.0

It is evident that for a fixed voltage and over a certain capacity range the photographic efficiency increases as a function of the capacity, ultimately, of course, reaching a maximum value. Extrapolation indicates that in this particular case this maximum is reached at approximately 3 μf.

Figures 21 and 22 show representative curves obtained with a Siemens S.F.2 tube under two different working conditions. For Fig. 21 the condition was as used in the Ernest Turner Electrical Instruments studio flash equipment with 100-μf condenser at 2 kv, and with a 6-ft cable between the condenser bank and the tube. This curve shows a flash duration which is very long compared with that of the S.F.7 types of tube as, of course, is only to be expected. The rise time would undoubtedly be shorter but for the inductive effect of the length of cable.

In Fig. 22 curve A shows the result for the S.F.2 tube mounted as closely as possible to the terminals of a low inductance 24-μf condenser charged to 2 kv. Curve B, which is reproduced for comparison purposes, was obtained

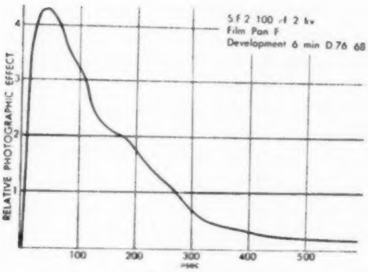

Figure 21

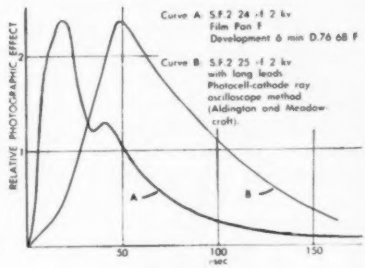

Figure 22

by Aldington and Meadowcroft[1] for the same tube using a photocell/cathode-ray oscilloscope system, the capacity in this case being 25 μf. The two curves have been plotted so as to have peaks of equal height. For the portions following the main peak the shape and duration are in general agreement, except that the secondary peak is absent from the photocell curve. There is a noticeable difference, however, in the rate of rise of light output shown by the two curves, the rise time in curve A being much shorter. This is not due to any fundamental disagreement, but to the fact that for curve B the circuit included comparatively long leads between the tube and condenser, which made the inductance greater than for curve A. This is illustrative of the very considerable prolongation of flash duration which is caused by the presence in the circuit of quite small inductance, and which can be seriously damaging to photographic results in experiments in which duration is critical.

The secondary peak which occurs during the decay from the main peak is again variable in position and magnitude from flash to flash as was found in the case of the similar secondary peak in the tail of the S.F.7 flash.

The results with the S.F.2 were obtained by running the disk at the comparatively slow rate of 3000 rpm. A slow film and low energy development were used to reduce the densities on the sensitometric strip to accurately measurable values. The much longer time scale rendered the whole derivation of the result much easier than with the short duration tubes.

Figure 23 shows curves for two experimental quartz tubes produced by Siemens, different capacities and voltages being used with each tube.[2]

The Accuracy of the Results

The accuracy of the results would be affected either by errors in the time scale or in the ordinate scale. The probable magnitude of such errors is discussed below.

The Time Scale. Errors of overall magnitude in the time scale are concontrolled by three factors: (a) the accuracy of the measurement of the speed of the disk; (b) in the case of camera photographs the measured reduction ratio in the camera, including film shrinkage; and (c) the accuracy of the microdensitometer movement.

Of these, (a) is by far the most serious. As mentioned earlier, the unsteadiness of the motor speed leads to an uncertainty in reading of ±2%. In addition the accuracy of the oscillator used, when checked against a known source, proved to be ±1.5%. As far as (b) is concerned, variatons in film shrinkage may amount to ±0.5%, because of the variety of emulsions and bases used. The reduction ratio was not measured for each of these individually. Over the small range used, (c) is negligible.

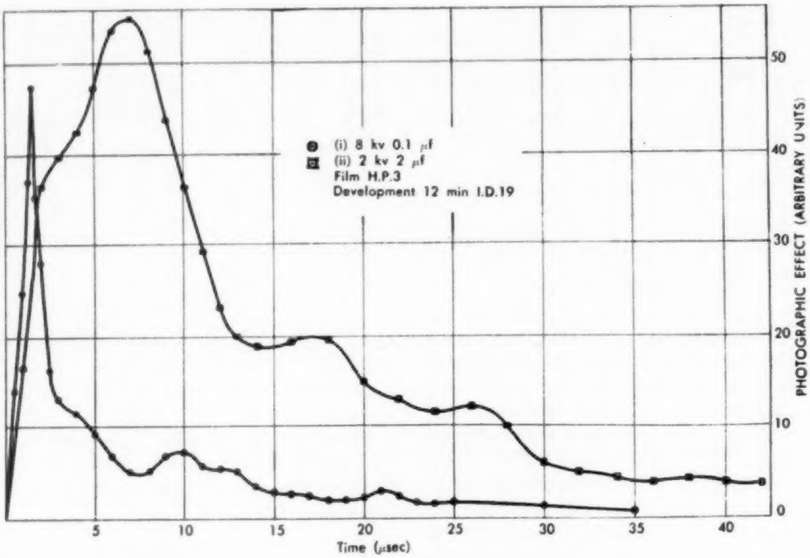

Figure 23

The maximum possible error from these causes is therefore ±4%. The linearity of the time scale is affected by variation of the speed of the disk during the period of the flash itself, which is certainly negligible, and also by the linear scan of the microdensitometer slit relative to the circumferential movement of the radial edge of the disk picture. Under the average conditions prevailing in the majority of the pictures this leads to an error in linearity of 0.5% which occurs toward the end of the scan, i.e. at the tail of the flash. This could be allowed for and corrected in the final curve, but the labor involved would not be justified by the very slight increase in accuracy resulting.

The maximum error in the time scale from all causes is therefore better than ±5%.

The Ordinate Scale. The primary factors affecting the ordinate scale are:

(a) Any departure from uniformity of processing between any one disk picture and its associated sensitometric strip.

(b) Accuracy of the transmission readings obtained from the microdensitometer.

(c) Error due to the slit of the microdensitometer not being parallel to the radial "edge" throughout its travel. This is separate from the error in the time scale mentioned above, although due to the same cause.

(d) Error due to finite slit width of the microdensitometer. This only occurs when the change in transmission with distance is nonlinear, i.e. particularly at the "shoulder" of the curve.

(e) Any unsharpness of the picture which might arise from a variety of causes.

Assessment of these errors is possible although in the case of that due to look of uniformity in processing only an estimate is possible, based on the consistency of the results. The effect of these errors on the final ordinate values obtained is, however, indeterminate, as

the processes, already described, of smoothing, transforming and differentiating the graphs is to some extent dependent on individual skill. The amount of smoothing necessary depends largely on the grain of the image and thus varies from film to film. In addition the accuracy of the differentiation varies with the slope of the graph and thus varies considerably along the final flash curve.

The smoothing necessary on the Transmission vs. Distance graph affects particularly the first sudden drop in density. This gives rise to an indeterminacy in the position of the zero of the time scale which may possibly amount to as much as 1 μsec, and in general will tend to increase the apparent width of the peak.

The difficulties of differentiation lead in particular to an uncertainty in the height of the extreme tip of the peak owing to the high slope of the Log Exposure vs. Time graph at this point. This can amount to as much as $\pm 20\%$ and will influence the estimation from the final flash curve of the effective time of flash if this is taken as that time within which the height of the curve has fallen to some specified fraction of its peak height.

In addition the errors in the ordinate scale caused by the primary factors (a) to (d) listed above will influence the curve to an unknown extent but this extent is certainly small.

From the above considerations it is evident that the most reliable criterion of the overall accuracy of the results must be based on the consistency of a number of curves obtained for the same tubes under the same conditions. The value of repeat experiments is somewhat lessened by the fact that, in general, the flashes vary to a slight extent in successive discharges, even with flashes from the same tube under exactly the same conditions. However, a great deal of experience was gained in the calculation not only of Figs. 10 to 23 but also from many similar and repeat experiments. From this experience the conclusion has been reached that any characteristics actually present in the flashes which cannot be reliably detected, and which are therefore not revealed by the curves as plotted, are certainly of no significance in practical photography.

Acknowledgments

The authors wish to thank Dr. J. N. Aldington of Siemens Electric Lamps and Supplies Ltd. for his assistance in supplying the experimental types of flashtube, and G. S. Moore of Ilford Ltd. for arranging for the controlled processing of the film in his laboratories during the early stages of the work.

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References

1. J. N. Aldington and A. J. Meadowcroft, "The flash tube and its applications," *J. Inst. Elec. Engrs. (London), 95, Part II:* p. 671, 1948.
2. W. D. Chesterman, D. R. Glegg, G. T. Peck, and A. J. Meadowcroft, "A new power stroboscope for high speed flash photography," *J. Inst. Elec. Engrs. (London), 98, Part II:* p. 619, 1951.

Properties of Polarizers for Filters and Viewers for 3-D Motion Pictures

By L. W. CHUBB, D. S. GREY, E. R. BLOUT and E. H. LAND

High-quality projector filters and viewers are essential to full audience enjoyment of 3-D motion-picture shows. Projector filters of improved type are now in production and constitute an excellent solution to the problems presented by high temperature and high light intensity. Being glass-laminated, they are easily cleaned and thus should last indefinitely. Viewers of excellent polarization characteristics, color neutrality and stability are available. Some minimum performance specifications are proposed, in the interest of insuring that all spectators are enabled to see 3-D presentations with full effectiveness. Optical "leakage" and chemical instability, present in some types of viewers are especially to be avoided.

THE MEDIUM now being employed in the exhibition of stereoscopic or 3-D motion pictures is polarized light. Polarizing filters are placed in front of the two projectors and polarizing viewers are worn by the spectators. If the orientations of the projector filters and viewer lenses are arranged correctly, each eye sees only that image intended for it.

Whereas natural, unpolarized light is believed to consist of wave vibrations in random directions at right angles to the direction of propagation, linearly polarized light consists solely of vibrations restricted to a single plane. Such a change in characteristic of a light beam may be accomplished merely by interposing a linearly polarizing filter. It is unavoidable that such a filter diminish the brightness of the beam, since the resolution of the many random electric vibrations into a single plane causes at least half of the energy to be lost, usually by absorption. The action of the polarizer is practically independent of wavelength, so that no appreciable change in color is involved. In a polarizing filter, that azimuth which corresponds to the plane of vibration of the emerging light is termed the transmission axis of the filter.

When two such polarizers are superimposed with their corresponding axes parallel, the light transmitted by the first is for the most part freely transmitted by the second. But if the filters are superimposed with their axes at right angles, the second filter blocks passage of substantially all the light which has emerged from the first. Thus parallel polarizers transmit light, crossed polarizers block it out.

The effects described are not dependent upon having the two filters superimposed or even adjacent to one another. They occur equally efficiently when the filters are widely separated, and indeed the principle continues to

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Presented on October 8, 1953, at the Society's Convention at New York by L. W. Chubb (who read the paper), D. S. Grey, E. R. Blout and E. H. Land, Research Laboratory, Polaroid Corp., 730 Main St., Cambridge 39, Mass.
(This paper was received Nov. 20, 1953.)

apply even when the light emerging from the first filter reaches the second filter by virtue of being reflected from a plane surface of appropriate type and orientation.

This arrangement is employed in the two-film system of 3-D presentation. The beam from a given projector is polarized by passage through a fixed filter placed close to the projection lens. The beam then strikes a polarization-conserving screen at near-normal incidence and is reflected to the patron — who wears a viewer having polarizing lenses oriented so that one will admit the light and the other will block it. Thus only one eye sees the image. Since the second projector's beam is polarized at right angles to the first, its light enters the patron's other eye. Thus the condition is fulfilled that each eye will see the image intended for it and will be unable to see the image not intended for it.

In such a system, two properties of the polarizing filters become of major importance: luminous transmittance, and leakage. The luminous transmittance, k_v, which is simply the transmittance found when the incident light is entirely unpolarized, should be as great as possible to permit maintaining adequate picture brightness, without placing too great a burden on the projector arc, the projector lens system and the theater screen.

A filter's k_v value may be measured directly by any of a number of simple methods, or it may be computed as half the sum of k_1 and k_2, the partial transmittances for 100% linearly polarized light whose vibration direction is chosen so as to give maximum and minimum transmittance, respectively.*

The theoretical upper limit on k_v is 50% if surface-reflection losses are neglected, or about 45% if reflection losses of normal magnitude are taken into account.

The leakage of a pair of crossed filters should be as small as practicable to minimize the amount of light from the "wrong" picture reaching a given eye. Any appreciable amount of unwanted light produces double-imaging, or ghost images, which interfere with the enjoyment of scenes containing high contrast. The leakage, or k_{vx} value, of a filter may be measured by carefully crossing two identical filters and measuring the transmittance of the pair for unpolarized light, or may be computed as the product of k_1 and k_2. In making the necessary measurements some care must be taken since the transmitted light, besides being very faint, may lie mainly at wavelengths near the extreme ends of the visual range of the spectrum. If a photocell is used as detector, its spectral response must be matched very closely to that of the eye. The light source used must closely resemble C.I.E. Illuminant C.†

So far we have been considering the projector filter and viewer filters in combination. Let us now consider each separately, in greater detail.

Projection Filters

In the art of manufacturing highly efficient linear polarizers,‡ it is well known that a filter's luminous transmittance, k_v, can always be increased at the expense of allowing some increase in the leakage, k_{vx}. Conversely, the leakage can be reduced at the expense of reducing the luminous transmittance.

Using appropriate materials and meth-

* For a technical discussion of the formulas applying to linearly polarizing filters, see C. D. West and R. Clark Jones, "On the properties of polarization elements as used in optical instruments. I. Fundamental considerations," *J. Opt. Soc. Am., 41:* 976, 1951.

† Discussed in *The Science of Color* by the Committee on Colorimetry of the Optical Society of America. Thomas Y. Crowell Co., New York (1953).

‡ E. H. Land, "Some aspects of the development of sheet polarizers," *J. Opt. Soc. Am., 41:* 957, 1951.

ods, it is possible to achieve simultaneously a high transmittance and a small leakage. For example, filters can be made which have luminous transmittance, k_v, of 43% and a k_{vx} value of 0.4%; or the manufacturing method may be altered so that k_v is 40% and k_{vx} is 0.1%; or the k_v value may be made 30% and the k_{vx} value approximately 0.001%, or one part in one hundred thousand. For filters prepared with especially great care, even more striking pairs of values may be obtained. The values given here are representative of what can be achieved in routine production.

As a result of trying many grades of projector filters in a large number of theaters, we are convinced that a good projector filter can and should have a luminous transmittance k_v of approximately 40% and a k_{vx} value of approximately 0.03%. While no formal standards are recommended at this time, it is clear that these particular goals are reasonable and desirable.

Besides having satisfactory polarization properties, the projector filter must be of high optical quality. It must have sufficient clarity and uniformity (resolving power) that when inserted in the projected beam it causes no appreciable change in the sharpness of the image appearing on the screen. It must be neutral in color, so as not to disturb the colors of the various objects portrayed.

Plastic filters meeting these requirements can be produced readily. However, such filters are difficult to clean, as they are easily scratched. Thus a periodic replacement scheme must be adopted, which is neither convenient nor economical.

Our present policy is to provide projector filters of essentially permanent type. These become a regular part of the projection-booth equipment, and can be cleaned simply whenever necessary. They are Polaroid K-sheet filters, whose resistance to heat is outstanding. (The filter was developed especially to withstand light and heat such as would be encountered by an automobile headlamp filter used for many years in Florida sunshine.) The K-sheet layer is laminated between two thin, polished pieces of plate glass. Thus the filter can be cleaned in the same way that an automobile windshield is cleaned. The optical resolution is excellent, corresponding to about 15″ of arc. The color is almost perfectly neutral.

In making and using glass-laminated projector filters some precautions have been found necessary if strain effects are to be avoided. Any permanent strain existing in the glass layers tends to produce birefringence, with consequent interference with the polarization of the beam. Even if the glass contains no permanent strain, strain may be engendered by the temperature gradient resulting when the filter is heated unevenly by the very intense beam incident on the central area. An internal temperature rise to about 100 C was found in one test, for a filter used in front of a projector operated at 90 amp. Cooling the filter with a small blower reduces the temperature gradient; reducing the thickness of glass layers helps further.

The thin-glass laminated type of filter now being produced, if cooled with a small blower, constitutes a highly satisfactory answer to the projector filter problem. Production of this filter is being expanded, and the needs of the industry should be fully met before long. These filters are inexpensive and there appears to be no reason to use filters of less perfect performance and durability.

The filters are usually supplied in frames with small spirit levels attached, to insure mounting at the correct orientation, i.e., with the upper edge of the frame strictly horizontal. When this is done, the filter's axis will have exactly the desired direction (+45° for the right projector filter and −45° for the left projector filter). If the pro-

jector axis is directed downward at an angle of more than 20° from the horizontal, the filter should be tilted so as to be perpendicular to the beam. Ordinarily, however, the filter is mounted in the vertical plane; this is easier to accomplish, makes for easier leveling of the upper edge of the filter and tends to reduce the amount of dust settling on the filter. The polarizing function is essentially unimpaired.

Whenever any appreciable variation in luminous transmittance exists among various filters from a given lot, the right and left filters are "paired" so that the two members of a pair have the same transmittance within a few percent. Any appreciable mismatch as to transmittance would tend to produce imbalance in brightness observed by a patron's two eyes, and would interfere with his enjoyment of the show.

Viewers

Unlike projector filters, the 3-D viewers are not a part of the theater property and pass out of the control of the exhibitor when given to the patrons. Their quality, however, is of just as great importance to realistic 3-D presentation as any other component of the exhibition. On the other hand, the number of viewers used is so large that the urge to achieve the greatest possible manufacturing economy is great.

Several unsatisfactory grades of viewers have been distributed in some theaters in recent months. In the effort to save fraction-of-cent amounts in the manufacturing cost of the viewer, the producers of these viewers have caused patrons to see shows under conditions far from optimum, which damages the growth of the 3-D medium.

Perhaps the most important optical characteristic of the viewer is its ability to transmit the wanted beam with good efficiency. A luminous transmittance of approximately 40% is easily obtained, and without allowing excessive leakage. Perhaps a value of 35% should be set as the lower limit, since a filter having less transmittance than this darkens the picture harmfully and unnecessarily.

The ability to exclude the unwanted beam is also of prime importance. Since a k_2-to-k_1 ratio as low as 0.6% is easily achieved, there is no reason to accept a leakage (k_{vx}) value greater than about 0.3%. Any greater leakage tends to produce ghost images which, in sharply focused, high-contrast scenes, tend to become a source of real annoyance. The annoyance is especially great if the spectator is seated near the screen, if there is substantial lateral separation between the right-eye and left-eye pictures on the screen, and if the screen is bright while the ambient-light level is low. Here, as for other specifications, an inferior product may seem reasonably acceptable in many situations, but in combination with other short cuts will produce a significant overall reduction in audience enjoyment. Any harmful short cut yielding only infinitesimal saving in viewer cost seems unjustifiable.

The following table lists k_1 and k_2 values for different wavelengths throughout the visible spectrum, for samples of *H* and *K* polarizers which have overall luminous transmittances of about 40%:

Wave-length ($m\mu$)	*H polarizer* k_1	k_2	*K polarizer* k_1	k_2
400	0.45	0.02	0.5	0.001
450	0.75	0.01	0.7	0.000
500	0.8	0.001	0.8	0.000
550	0.8	0.0000	0.8	0.0000
600	0.75	0.0000	0.8	0.0000
650	0.75	0.0000	0.85	0.0000
700	0.8	0.0000	0.9	0.01

The axes of the viewer lenses are intended to be at right angles to one another, at plus and minus 45° from the horizontal. Our experience indicates that a 4° variation in the intended 90° angle between the lenses' axes is permissible. Greater variation may produce appreciable double-imaging.

Since many persons presumably tilt their heads slightly and unconsciously

so as to roughly minimize double imaging, it is probably reasonable to allow some variation in the disposition of the centerline of the "v" orientation of the two filters. It is believed that the centerline, nominally vertical, may be allowed to deviate 4° either side of the vertical. As it is a simple matter to make the lenses essentially neutral in color there would appear to be no reason for accepting viewers off-neutral to any appreciable extent.

As in the case of projector filters, optical quality of viewer polarizers should be uniformly high. Such defects as haze, striae, orange peel and waviness should be minimized to avoid any appreciable effects on resolution and visual acuity.

The chemical stability of certain types of viewer lenses appears to be low. For reasons of economy, viewer lenses usually consist of thin plastic sheets, with no protective layers of glass. Furthermore, the polarizing layer itself may be an exposed layer. For such viewers it is essential that the polarizing layer have good stability. Otherwise, the filters may deteriorate during storage, especially in warm, damp environments. Also, handling by the patrons' fingers, especially during hot weather, may cause the polarization to fade before the show is half over. Many such instances have been encountered, and the damage done is especially great if the patron attributes his difficulty to 3-D in general, instead of to faulty viewers. We believe it necessary and desirable to specify that viewers shall not show appreciable deterioration in the respects discussed in the previous paragraphs, when exposed to high temperature combined with high humidity. We propose as a test procedure a 48-hr exposure to 90 F, with the relative humidity 95%.

Acknowledgments

In our projector filter and viewer programs we have been greatly encouraged by R. T. Kriebel and J. Turner, and by the skill and perseverance of our technical group, especially J. Falt, L. Farney and H. Buzzell.

Discussion

Henry Roger (*Rolab Photo-Science Laboratories*): Are there any data available as to comparison between the sheet polarizers and the old-type Nicol prisms with regard to transparency and polarization?

Mr. Chubb: I have no data on hand, but there are data available which we would be very happy to supply.

Anon: The picture *Kiss Me Kate* has been completed in 2-D and 3-D, which leads to the question of whether there is any possibility of reducing the density of these filters. Losses of nearly 60% in 3-D have been reported, and also a great deal of degradation in color.

Mr. Chubb: Well, as I pointed out, it is necessary for a linear polarizer to absorb at least 50% of the light, and, when reflections are taken into account, 55%. We are recommending that the transmission be no lower than 35% and preferably 40%. That comes about as close to satisfactory performance as you can expect when you take into account the fact that the k_{vz} or value of the light extinction properties of the polarizers must be kept very low.

Anon: The difference in color was very noticeable when *Kiss Me Kate* was switched from 2-D to 3-D on adjacent screens. Everything seemed considerably duller, with up to 130 amp of light at times, on a very large screen.

Mr. Chubb: With regard to color, I can only say that our projector filters and viewer filters are essentially neutral. I do not know what type you were using. I had occasion to see that picture in Hollywood and John Arnold thought that under the conditions in which it was presented there it was quite fine.

Anon: The preference of many Hollywood viewers for this picture in 2-D cannot be ignored . . . . Normal neutral filters are used to soften effects. Instead of using small stops when shooting, the filter is used to reduce contrast. Even in Technicolor we use a filter. So it would seem that polarizing filters could be similarly employed.

Mr. Chubb: I think we all agree that one of the unfortunate things about the use of polarizers in 3-D projection is that they do absorb light. We must build up the arc intensity, use low *f*-number lenses, and take every dodge that we can to get light on the screen. We must use not only 3-D screens, but 3-D screens which have high reflectivity. That is a real problem. What we are recommending here is that the very most be made out of the art of polarizer manufacture so that light on the screen will not be compromised nor colors distorted or softened.

Screens for 3-D and Their Effect on Polarization

By W. A. SHURCLIFF

A 3-D motion-picture screen, besides reflecting the two incident beams with good gain throughout a reasonably wide lobe, must conserve the polarization tagging of the beams. Tests on 100 screen samples show that the majority of screens of normal design meet these requirements excellently — for viewing angles not exceeding about 20° from the screen normal. Thus these screens are very satisfactory for use in narrow theaters. For 45° viewing, such as occurs in wide theaters, screens of this type usually have rather low gain and their polarization defect values approach a harmful level. Lenticulated screens, however, tend to avoid these difficulties and thus go a long way toward solving the wide-theater problem. There are several different designs of lenticulated screens, each having certain advantages and disadvantages.

A SCREEN for use at 3-D motion-picture shows must perform two functions: (1) reflect the two beams with adequate brightness gain throughout a lobe of adequate width, and (2) conserve the polarization of the two beams so that their polarization tagging will be intact when they reach the spectator.

The first function, serving as a diffuse reflector with adequate brightness gain and lobe width, has been studied by many investigators; an excellent summary of the general problem, terminology, etc., has recently been published by the Motion Picture Research Council.[1] The present survey has been focused mainly on the second function: conserving the polarization of the beams.

During the last six months, more than 100 screen samples have been tested. About one-third of these were commercially available screens, and the remainder were developmental samples submitted by screen companies, aluminum paint companies, etc. Some samples were submitted with the understanding that their exact identification would be withheld. A number of the samples had perhaps aged appreciably before being tested, and in these instances especially, the results apply, of course, only to the particular samples at hand.

The results on brightness gain will be presented first, to set the stage for the polarization conservation results.

Brightness Gain

The brightness measurements were made with specially designed test instruments requiring samples only 2 in.

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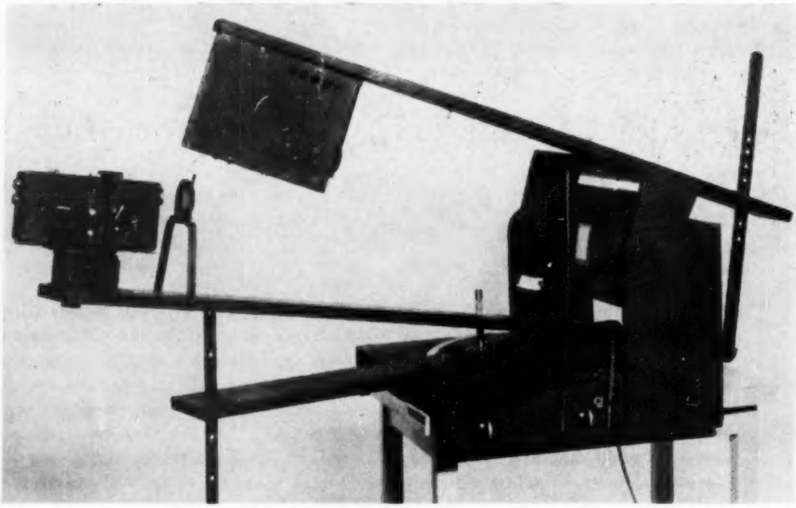


Fig. 1. Model 2 Screen Tester, general design.

square. The most versatile instrument, shown in Fig. 1, permitted setting the screen at any desired "tilt" angle from the vertical; also it permitted selecting any desired "projector" elevation angle from 0° to 35°, any desired spectator elevation angle from 0° to 35°, and any desired spectator *lateral* angle from 0° to 60° on either side of the screen normal.

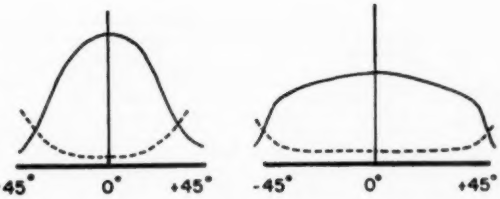
The "projector" consisted of a clear-envelope tungsten lamp used without lenses — to insure uniform illumination across the sample. The various brightness values were determined with the aid of a Luckiesh-Taylor footlambert meter.

At suitable intervals a clean block of magnesium carbonate was placed in the sample position and measured while being illuminated and viewed along the normal. The brightness value so obtained was arbitrarily called 100%, and the measurements made on screen samples were related to it. The resulting brightness ratios, referred to here as brightness *gain*, vary, of course, not only with the type of screen but also with the particular choice of sample tilt, projector elevation angle, spectator elevation angle, and spectator lateral angle (viewing angle). It should be emphasized: that the values refer to *brightness*, not *intensity* as in some other investigations; also that the method of measuring the brightness of the magnesium carbonate block differs slightly from that sometimes employed.

The results obtained may be summarized readily if we confine our attention to measurements made under the following "standard" conditions: (a) screen vertical, (b) projector elevation angle 0°, (c) spectator elevation angle 0°, and (d) spectator lateral angle 0°, 15°, 30° and 45° from the normal. The results are listed in the first four columns of Table I.

Screens of Normal Design. The first section of the Table deals with screens of "normal" design, i.e., smooth or near-smooth plastic sheets, plywood panels, etc., to which diffusing aluminum coatings have been applied. The second section deals with lenticulated screens,

Fig. 2. Brightness gain vs. viewing angle for standard (left) and lenticulated (right) 3-D screens. Dotted curve represents the polarization defect.



and the third deals with woven fabrics whose face consists of threads each of which appears to have its own individual aluminum coating.

The results shown in the first section of the Table indicate that screens of normal design almost invariably have a simple, bell-shaped gain curve, as shown in Fig. 2, with high gain at the center (viewing angle of 0°) and with gain falling off rather rapidly at viewing angles of 15° to 45°. It has recently been shown[2] that fall-off may be described approximately by an expression of the type: $(\cos \theta)^{s-1}$, where θ is the viewing angle and s is called the screen constant. The gain at 0° varies widely (150% to 800%) from one design of screen to another; and, as expected, the screens which have the highest gain at 0° suffer particularly rapid fall-off between 15° and 45°. Most of the commercial screens are of this type, and almost any desired 0° gain can be attained by proper choice of brand.

Surprisingly enough, almost all the screens of this group have approximately the same gain at 45°. And, unfortunately, the gain value in question is low, being 30% to 40% in most instances. For most theaters this is perhaps of little consequence; but it is a real embarrassment to theaters having unusually great width-to-length ratio ("wide" theaters). For such theaters an entirely new principle of screen design, known as lenticulation, seems called for.

Lenticulated Screens. Section 2 of the Table presents the results for lenticulated screens. These screens, instead of relying on randomly arranged microscopic particles of aluminum to spread the beam adequately, employ an array of *macroscopic* facets of carefully controlled (curved) shape. The facet surface may consist of clean bright aluminum, or a diffusing coating of aluminum paint, or a diffusing coating of plastic overlying a bright metal surface. Each type of design has its peculiar advantages and disadvantages.

Sample 34, a small experimental sample,* illustrates the very large amount of light that can be made available if the inefficiency usually associated with diffusing coatings is avoided — by dispensing with the diffusing coating entirely. The sample consists simply of a piece of bright, smooth aluminum foil in which thousands of small cup-shaped facets were embossed in a completely regular array by pressing against a specially machined mold. Each facet is rectangular in shape, 0.100 in. wide by 0.050 in. long, and the curvature corresponds roughly to part of a sphere of $\frac{1}{8}$-in. radius. The gain at 0° is 100%, which is scarcely notable; but instead of being a maximum here the gain actually increases with lateral angle up to 45°, where the gain is 400%. Beyond this angle the gain drops very sharply. The unusual brightness at 45° results in an annular "hot-spot" or "halo" which, of course, is undesirable. The halo is a result of the fact that each facet has a shape which is approximately, but not exactly, part of a sphere; and for every facet the de-

* This sample was prepared with the advice and encouragement of D. S. Grey.

Table I. Brightness Gain and Polarization Defect.

Screen	Brightness gain (%) for viewing angle of 0°	15°	30°	45°	Polarization defect (%) for viewing angle of 0°	15°	30°	45°
Section 1. Screens of Normal Design								
1. Normal type, Co. A	130	100	60	30	1.0	1.5	2.5	4.5
2. Normal type, experimental, Co. B	180	140	80	30	1.	2.	3.	5.
3. Normal type, experimental, Co. B	110	80	60	40	2.	3.	4.	7.
4. Normal type, experimental, Co. C	140	130	80	40	1.2	1.3	2.0	3.5
5. Williams, earlier type	280	210	70	30	0.2	0.4	1.0	3.5
6. Aluminized cardboard, Co. D	420	170	45	20	0.2	0.3	1.2	4.0
7. Aluminum paint on Masonite Prestwood, smooth side, Co. E	220	170	60	30	0.5	0.5	1.3	3.0
8. As above, but rough side, Co. E	60	60	50	50	4.0	4.0	4.0	5.5
9. Aluminum paint on plywood, Co. F	220	180	100	50	0.5	0.8	1.3	3.0
10. Aluminum paint on aluminum, Co. F	450	170	50	20	0.2	0.6	1.2	4.0
11. Beaver board aluminum-painted, Co. G	120	...	...	50	1.7	...	...	5.5
12. As above, but different paint formula, Co. G	100	90	70	50	2.0	2.0	2.5	3.3
13. Raytone, earlier type	110	90	60	35	2.0	2.5	4.5	6.0
14. Walker, earlier type	90	75	60	30	2.5	2.5	3.5	6.5
15. Normal type, experimental, Co. H	130	95	60	40	1.0	1.0	1.5	3.0
16. Da-Lite, earlier type	75	75	50	40	2.0	2.5	3.5	6.5
17. Normal type, experimental, Co. I	190	145	65	30	0.4	0.5	1.0	2.5
18. Aluminum paint on aluminum, Co. J	300	180	70	25	0.2	0.4	0.8	2.5
19. Aluminum paint on cardboard, Co. K	290	200	85	30	0.3	0.4	0.8	2.3
20. Raytone, earlier sample	270	180	90	30	0.4	0.5	1.2	3.1
21. Williams "Satin Silver #303"	310	260	95	45	0.3	0.3	0.8	2.5
22. Williams "Bright Silver #304"	650	360	70	25	0.2	0.3	0.8	3.1
23. Da-Lite	90	80	65	45	1.5	2.0	2.5	4.5
24. Bodde, earlier sample	370	250	75	30	0.3	0.4	1.2	3.5
25. Normal type, experimental, Co. L	330	180	70	40	0.4	0.6	2.0	4.5
26. Aluminum painted plywood, slightly rough surface, Co. M	310	...	...	35	0.3	...	...	2.5
27. As above, except smooth surface, Co. M.	870	250	...	15	0.1	...	...	4.0
28. Raytone Type 06, fresh sample	290	220	105	40	0.4	0.4	1.2	2.2
29. Walker #1, fresh sample	250	180	75	30	0.4	0.5	1.1	3.5
30. Walker #2, fresh sample	155	125	75	40	1.0	1.1	2.0	4.5
31. RCA All-Purpose	290	200	70	30	0.4	0.5	1.5	4.5
32. Aluminum coated with aluminum paint, Co. N	310	190	65	33	0.3	0.5	1.5	4.0
33. Same as above, slightly different design	550	215	60	23	0.2	0.5	1.6	4.0
Section 2. Lenticulated Screens								
34. Lenticulated, regular pattern clean bright aluminum facets, Polaroid experimental sample	100	100	200	400	0.3	0.3	0.2	0.2
35. As above, except facet shape is slightly different	95	80	80	90	0.5	0.5	1.0	1.0
36. As above, except facet shape is slightly different	180	150	120	120	0.4	0.4	0.4	0.4
37. As above, except facet shape is very different	600	500	200	100	0.2	0.3	1.0	3.0
38. As above, except randomly located facets of random shape	390	100	60	60	0.6	2.5	3.5	3.5
39. As above, but slightly different design	125	110	105	70	0.5	0.5	0.7	1.5

Table I. Concluded

Screen	Brightness gain (%) for viewing angle of 0°	15°	30°	45°	Polarization defect (%) for viewing angle of 0°	15°	30°	45°
40. Lenticulated, diffusing coating; experimental, Co. O	280	210	160	80	1.0	1.5	3.0	10.
41. As above, but different coating	450	450	180	50	0.1	0.1	0.5	4.0
42. Lenticulated, old sample, Co. P	320	180	60	25	0.5	1.2	4.5	22.
43. Lenticulated, old sample, Co. Q	105	105	105	45	0.7	0.7	0.8	2.2
44. Lenticulated, Miracle Mirror, old sample (?)	170	145	110	90	0.4	0.5	0.6	1.2
45. Magnaglow-Astrolite	175	155	135	110	1.6	2.0	2.5	4.7
Section 3. Coarse-Weave Screens								
46. Fiberglas cloth, not aluminized	60	60	60	60	20.	...	...	35.
47. Same, except each thread has an aluminum coating	50	50	50	50	10.	...	...	10.
48. Cloth sprayed with metal of unusual type	100	...	...	30	4.0	...	...	7.0
49. Aluminized cloth	70	60	50	30	10.	15.	20.	30.
50. As above, but different kind of surface	70	60	50	55	3.0	4.0	5.0	7.0
51. Coarse-weave cloth, aluminized	55	45	40	35	4.5	5.0	6.5	8.0
52. As above, but different type of cloth	110	80	35	15	3.0	4.0	6.5	14.0

parture from spherical shape is the same. It may be concluded in general that if each facet of a screen is to be of smooth aluminum and if all facets are to have the identical shape, any *microscopic* error in facet shape may produce intolerable *macroscopic* patterns.

The difficulty is avoided in Sample 39, an experimental sample in which the smooth aluminum facets have been made with randomly varying shapes and tilts. Here the gain is 125% at 0°, and still has the moderately large value of 70% at 45°. Because the facets are of random shape and tilt, no harmful halos result.

Sample 38 is of somewhat similar design, and has a gain of 390% at 0°. Sample 37 has a gain of 600% at 0° and 100% at 45°, but its lobe is extremely slender in vertical cross section.

In Sample 45, a sample of Magnaglow Astrolite screen, the bright, curved, metallic layer appears to be coated with a diffusing plastic layer, which presumably helps insure freedom from halos. The curvature of the metallic layer is different along lateral and vertical cross sections, so that the screen's lateral lobe is wider than its vertical lobe — in accordance with the requirements of most theaters. The lateral lobe is of considerable width: the gain at 0° is 180% and at 45° the gain is still as high as 110%; or about *three* times as great as for typical screens of normal design.

In Sample 44, a sample of the Miracle Mirror screen, the metallic layer appears to be of diffusing type, rather than smooth. The gain is 170% at 0° and 90% at 45°, this latter value again comparing very favorably with screens of normal type. (Unfortunately, attempts to obtain a really recent sample of this type of screen were unsuccessful.)

In general, lenticulated screens go a long way toward providing reasonably good gain even at viewing angles as great as 45°. Such screens appear uniquely capable of filling the needs of very wide theaters, and may prove useful in other theaters also.

Coarse-Weave Screens. The third section of the Table deals with screens whose front surfaces consist of distinct threads, each with its own aluminum coating. The samples were not noteworthy as

regards gain and tended to produce lobes of irregular cross section.

Polarization Conservation

As is well known, the two projected beams of a 3-D motion picture are distinguished by their azimuth of linear polarization. By convention, the beam carrying the right-eye picture is polarized with its electric vibration at an azimuth of +45° as judged by the projectionist looking past the projectors towards the screen. The left-eye beam is polarized at −45°. The lenses of the viewing spectacles consist of polarizers oriented so that the right eye receives only light having the +45° azimuth, and the left eye receives only light having the −45° azimuth. Thus if the projector filters, the screen and the viewers perform perfectly, the right eye will see only the picture intended for it, and the left eye will see only the picture intended for it; accordingly a stereoscopic, or 3-D, effect results.

Unfortunately, most actual screens degrade the polarization of each beam slightly, by virtue of diffraction effects, multiple reflection effects, birefringence effects, etc. As a consequence each eye of the spectator receives a little light from the beam meant for the other eye. The left eye, for example, will see brightly the picture meant for it and dimly the picture intended to be withheld from it. The latter picture, called the ghost image, is usually of low intensity and therefore of no practical consequence. However, the ghost tends to be more pronounced in situations where a white object is seen against a black background; here one edge of the ghost image overlaps the black background, enhancing the conspicuousness of the ghost.

A simple way to characterize a ghost of this most conspicuous type (white object on a black background) is to state its brightness ratio, or ratio of (a) brightness of the ghost image in an area where it stands alone, on a black background, to (b) brightness near the center of the image, where the right-eye and left-eye images overlap.

Ghosts can result from use of poor projector filters, poor viewers, or poor screens. It has been shown, however, that projector filters and viewers meeting very exacting standards are available and make only a negligible contribution to ghost images.[3] Thus the polarization conservation of the screen remains as the factor of principal interest.

The polarization conservation property of a screen may be defined in either of two ways: (1) affirmatively, so that a higher number indicates a better screen, or (2) negatively, in which case a higher number indicates greater damage to the polarization of the incident beams. The latter definition has been found more convenient, since smaller numbers are involved and they approach zero as the design of the screen becomes more nearly perfect. The quantity in question, called "polarization defect of the screen," or simply "defect," G, is defined with respect to the composition of the beam reflected from the screen in a specified direction when the incident beam is 100% polarized at 45° and is incident on the screen at a specified angle (0° from the normal ordinarily). More exactly, it is the ratio of (a) amount of reflected light corresponding to the azimuth of minimum energy, to (b) total amount of reflected light. Roughly speaking, defect is the fraction of the reflected light which has the unwanted polarization.

Thus defined, the term *defect* has a direct and useful interpretation, being identically the brightness ratio of the ghost of a white object on a black background. For example, if the defect is 3%, the ghost's brightness ratio is 3% also. (The ratio will be even greater, of course, if the projector filters or viewers are imperfect, or if the viewers are worn at a nonoptimum angle.)

No formally established tolerance on

screen defect exists. Deciding on a suitable upper limit will be difficult since the noticeability of ghosts presumably varies with circumstances, such as screen brightness, contrast and density range present in the film, sharpness of focus, size of picture and distance of the observer. The spectator's absorption in the story is presumably an important factor also. Informal tests, however, suggest that a screen defect of ½% permits essentially full enjoyment of the show, and even a 1% defect may be regarded as acceptable until better screens become available.

Since little or no information was available in the literature as to typical values of defect for commercially available 3-D screens, a general survey of the situation was undertaken. The same samples discussed above were measured, and the same equipment was used. For the present purpose, however, a polarizing filter was placed in front of the "projector," with the transmission axis at +45°, and a similar, rotatable, polarizer was placed just in front of the observer (meter). (Both polarizers were of sufficiently high quality that for purposes of the present tests they were essentially perfect; for example, a pair of such filters had a transmittance of less than 0.01%, when crossed.) For each viewing angle, measurements were made with the latter polarizer oriented so as to give the minimum reading (m) and then re-oriented so as to give a maximum reading (M). The defect is then easily computed, being $(m)/(m + M)$.

The defect values obtained are presented in Table I, in the second group of four columns.

Screens of Normal Design. It is immediately apparent that typical screens of normal design have defect values of approximately 0.5% at 0° viewing angle. But it is equally apparent, as suggested by Fig. 2, that the defect increases almost tenfold as the viewing angle approaches 45°, where the defect is typically 3% to 5%. This is somewhat disturbing as it means that side-aisle spectators, when viewing scenes presenting maximum contrast, will be subjected to ghosts of 3% to 5% brightness ratio.

Inspection of the original brightness measurements shows that, for screens of normal design, the minimum reading m is almost independent of the viewing angle. This means that the defect increases with viewing angle — not because of *increase* in unwanted light but because of very large *decrease* in wanted light. Such a screen may be thought of as distributing unwanted light rather uniformly throughout a very wide lobe, while distributing wanted light throughout a narrow lobe. Perhaps the most obvious approach to improving the situation is to increase the amount of wanted light distributed at viewing angles of 30° to 45°. This again suggests lenticulated screens.

Lenticulated Screens. As expected, lenticulated screens appear capable of holding the defect value to a very low limit even for 45° viewing. Sample 34 (smooth bright aluminum facets) has a defect of 0.3% at 0° and only 0.2% at 45°.

Sample 45 (Astrolite, employing a plastic coating) has a defect of 1.6% at 0°, which is somewhat disappointing; at 45° the defect is 4.7%. If some means could be found for reducing the defect values, this screen would have a particularly striking performance.

Sample 44 (Miracle Mirror) has a defect of 0.4% at 0° and 1.2% at 45°. These values are unusually low.

It would appear reasonable to hope that some design will eventually be found which provides the wide brightness lobe of the Astrolite screen with the very small defect of the Miracle Mirror screen. A screen with these properties should be a superb solution to the wide-theater problem.

It may be, of course, that a hybrid design, intermediate between normal type and lenticulated type, would have some real merit. Indications were obtained that even in an otherwise normal screen the provision of a simple and informal pattern of small rounded hills and valleys made an enormous improvement for the observer at 45°.

Coarse-Weave Screens. As shown in Section 3 of the Table, poor results were obtained for nearly all samples whose front surface consisted of distinct threads, each with its individual aluminum coating. Polarization defect values of 5% to 15% were not uncommon.

In general, large defect values were found for all surfaces containing distinct threads, distinct grains, or sharp crevices. Presumably multiple reflections occur in all such instances, leading to an appreciable amount of depolarization. To avoid such difficulties it seems necessary to use a gently rounded surface with no sharp intervening crevices.

Plastic coatings on top of a metallic coating may exhibit slight birefringence in addition to causing some multiple reflections. Such coatings must be engineered carefully if they are to be successful.

(A number of experimental rear-projection screen samples were tested also. Besides having narrow transmission lobes they tended to produce large polarization-defect values.)

Conclusions

Screens of standard design, although having excellent gain and polarization conservation when illuminated and viewed near the normal, show poor gain when viewed at 45°. Hand-in-hand with the poor gain, a polarization defect of 3% to 5% is almost invariably found at 45°.

The lenticulated screen holds promise of being an excellent solution to the gain and defect difficulties at 30° to 45°. Use of clean, specular facets makes for particularly high gain and low defect, but may produce "hot-spot" problems. Employing microdiffusing mechanisms as adjuncts to the curved facets avoids these problems, but may increase the defect slightly.

It seems probable that further development of the lenticulated screen will produce a very satisfactory answer even for very wide theaters. For narrow theaters, screens of normal type appear to be very satisfactory in most instances.

Acknowledgments

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References

1. Informational Bulletin No. 7, "Progress Report on All-Purpose Theater Screens," Motion Picture Research Council, Inc., Hollywood, Calif., Aug. 5, 1953.
2. Armin J. Hill, "A first-order theory of diffuse reflecting and transmitting surfaces," *Jour. SMPTE, 61:* 19–23, July 1953.
3. L. W. Chubb, D. S. Grey, E. R. Blout and E. H. Land, "Properties of polarizers for filters and viewers for 3-D motion pictures," *Jour. SMPTE, 62:* 120–124, Feb. 1954.

Discussion

Ben Schlanger (*Theater Consultant, New York*): Both of the lenticulated screens mentioned are in symmetrical and linear pattern. What experience have you had with random lenticulation, with scattered directional effects?

Mr. Shurcliff: We've tried some experimental screens in which all the facets or cups were put on with random shapes and random orientations, and they looked very promising to me.

Anon: Do you have any information on rear-projection screens?

Mr. Shurcliff: I tried a few rear-projection screens and they seemed very disappointing. The brightness seemed to fall off quite rapidly and the polarization defect increased almost astronomically. I'm not sure I tried the best ones, but the ones I got hold of were quite disappointing.

George Lewin (*Signal Corps Pictorial Center*): When you mentioned the cloth screens, you said that polarization seemed to be greater in a vertical direction and also in a horizontal direction, because that's the way the threads ran. From limited experience, I should ask what's wrong with turning the screen 45° so the threads run the way you want them to?

Mr. Shurcliff: I'm afraid that if you turn it 45° you find good brightness diagonally but poor brightness vertically and horizontally. In any case, even though the brightness were adequate, we invariably have found in the coarse-woven samples we have tried, that the polarization defect is very large, being typically 10% and sometimes 20%, so that the double-imaging is intolerable. My feeling is that the light gets reflected several times in between the threads and loses its polarization.

W. W. Lozier (*National Carbon Company*): I saw one screen in particular where paneling or perhaps seams, I don't know which, made the screen surface visible. And in viewing a 3-D picture I had the impression that I was looking through a veil in order to see the picture in which most of the action was behind the screen. Your analysis doesn't take any account of that kind of defect, does it?

Mr. Shurcliff: I am afraid I have studied only brightness and polarization, but not the seams. The seams are very important, of course.

Dr. Lozier: It wasn't only seams, but paneling and the sort of thing that gave streaks that made it look as though you were looking through a curtain.

Leonard Satz (*Raytone Screen Corp.*): Just as there are problems in the transmission of the filters, we feel that we have problems in producing the type of screen that the exhibitor wants and which the patron is waiting to see. We have a problem in getting a screen of uniform surface and one which will give the greatest brightness to the most important section of the theater. We can all go to lenticulated surfaces. Designs are available which can do that very successfully, but if we do, we sacrifice the light that we need for good brightness and brilliance in the most important parts of the theater for those seats that we feel are the less important seats in the theater.

Mr. Shurcliff: That's a very good point.

John Volkmann (*RCA Victor Div., Camden*): What is the maximum percentage of polarization defect which you consider tolerable?

Mr. Shurcliff: Well, we at Polaroid feel that we would like to see the polarization defect no greater than very roughly 0.5%. We don't have a final figure to recommend, but we think it would be in that neighborhood. Of course, in scenes where the contrast is low, or the focus is not perfect, a somewhat larger defect seems to be not too harmful. But we would like to see it get down pretty close to 0.5% or less.

Howard Karp (*Radiant Manufacturing Corp.*): I'd like to correct a possible misunderstanding before it goes further and take the side of Dr. Shurcliff. We do not lose any light, as was just indicated, by using a lenticular surface.

Mr. Satz: I didn't mean loss of light. What I meant to infer was that greater brightness values are available without lenticulation. That I have proven to myself many times and independent laboratories have proved it for me. We know that we can get higher brightness gains and we know also that for a screen to give the proper performance in a theater with the use of projection-type filters and eyeglasses we have to have brightness gains that are quite high. Now, to compromise and take what you might consider a favorable brightness gain and then change the characteristics so as to lose brightness and snap in the picture, is to a screen manufacturer unforgivable. We feel that for stereo and wide-angle projection we have to give a brightness value to the theater that is equivalent at least to the best type of ordinary projection on smaller, white diffusive screens. That is very difficult to do unless you have a high brightness gain. At the moment we know of no way of getting it together with good brightness at the sides; nor can we get seamless construction by going at this time to lenticulated types of patterns.

Equipment to Measure and Control Synchronization Errors in 3-D Projection

By R. CLARK JONES and WILLIAM A. SHURCLIFF

Equipment is described that permits the projectionist to obtain and maintain perfect synchronism in the projection of 3-D motion pictures. This is accomplished without stopping the show or otherwise interfering with the continuity and quality of the projection. The equipment is of two basic types: synchronization monitors and synchronization controls. The monitor is used to measure the direction and amount of the synchronization error, and the control is then used to correct the error.

PRESENT MEANS of projecting 3-D motion pictures involve the simultaneous projection of two separate strips of film in two separate projectors. In order to project the two films in the same time relation as that in which they were exposed, it is necessary that the two projectors be synchronized, and that the two films be started in synchronism. It is further essential that if for any reason it is necessary to shorten one of the films, the other film must be shortened by exactly the same amount in the corresponding position.

Those of you who have seen a number of 3-D motion pictures, not in review rooms, but in ordinary theaters, are uncomfortably aware that all theaters do not always present 3-D pictures in perfect synchronism.

Present means of projection are inflexible. If the films are started wrongly, or if an incorrectly compensated splice occurs, the synchronism is imperfect and nothing can be done to correct it, short of stopping the show and rethreading on footage marks. Or, if the means used to interlock the two projectors introduces a fixed or variable error, there is nothing the projectionist can do to offset this error. A check of over 100 theaters has shown that about one-fourth of all 3-D motion-picture presentations have a disturbing lack of synchronism.

Synchronization errors are conveniently described in terms of the number of frames by which one projector is ahead of the other. If, for example, the right projector is running $\frac{1}{24}$ sec ahead of the left projector, the synchronization error is described by saying that the right projector is leading by one frame.

We have conducted a good many tests with a variety of 3-D films and with a number of observers to find out how serious synchronization errors are. The more critical observers find a synchroni-

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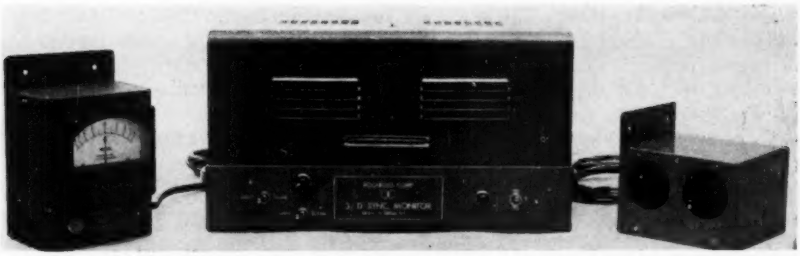


Fig. 1. Showing the Polaroid 3-D Electronic Sync Monitor, Model 21. The meter is at the left, and the photocell housing is on the right. The main electronic chassis (with 18 tubes and 5 relays) is in the center.

zation error as large as $\frac{1}{4}$ frame to be objectionable when fast action is involved. Uncritical observers may tolerate as much as $\frac{1}{2}$ frame if the action is not very fast. There is no question that all observers find an error of one frame to be seriously disturbing. With an error of one frame, all moving objects acquire a watery, transparent appearance that is very characteristic. This effect makes moving lips, blinking eyes and fast body motions look peculiar and disturbing.

A one-frame error, however, is not sufficient to make moving objects appear double; this requires an error of at least 2 or 3 frames.

Error of splicing and of threading up can, of course, produce synchronization errors of any number of whole frames. We have observed errors of 2 or 3 frames due to incorrect threading, and errors of 4 or 5 frames due to incorrect splicing of the film. Film exchanges regularly find splicing errors in 3-D films that are received back from theaters.

All the electrical interlock systems that we have seen have synchronization errors of not more than $\frac{1}{2}$ frame. A typical error is $\frac{1}{4}$ frame. Mechanical interlocks, however, may have much larger errors. We have encountered two installations of the flexible-cable type that have errors exceeding one frame.

All the synchronization errors described above were measured with specially developed synchronization monitors, of the types described below.

Synchronization Monitors

When synchronization monitors were first being developed, the possibility was explored of marking the films so that light signals could be picked off at the two projectors. These signals would be received by two phototubes, and the relative time of the two signals would be compared electronically.

The method was attractive at first, but was abandoned for two reasons: (1) Extensive modification of existing projectors would be required to pick off the light signals, each different type of projector requiring separate treatment; (2) The time delay between the development of the method and its effective use would be too great.

Accordingly, we turned our attention to methods that do not depend upon any special marking of the film.

Polaroid 3-D Electronic Sync Monitor, Model 21

The first Sync Monitor to be developed, the Model 21 device, is shown in Fig. 1. It includes a phototube housing, a large meter and the main electronic chassis. This latter component is fairly complicated, involving 18 tubes and five relays.

The Model 21 makes up for its complexity, however, by its simple, clean-cut performance. All that is necessary is to place the phototube housing so that it can look at the screen, plug the power cord into a source of a-c power, and throw the power switch. From then on, the meter reads the direction and amount of the synchronization error. If there is no error, the meter reads exactly zero, at the middle of the scale. If the right projector is ahead, the meter reads to the right of center, and if the left projector is ahead, the meter reads to the left. The meter covers the range between 5 frames error in one direction to 5 frames in the other direction. The meter scale is expanded in the middle so that small errors can be read easily and accurately.

If the two films have a synchronization error of more than $\frac{1}{4}$ frame in either direction, a buzzer starts to sound, and continues to sound until the error becomes less than $\frac{1}{4}$ frame.

The Model 21 Sync Monitor is responsive to sudden scene changes. Whenever there is a scene change, there is a sudden change in the overall screen brightness. The Model 21 responds to these sudden changes of screen brightness, while at the same time it completely ignores the 48 cycles/sec modulation of the screen brightness by the projector shutters.

The phototube housing contains two phototubes. The light from the screen reaches each phototube through a polarizer, and an $f/1$ lens. The polarizers are oriented so that one phototube receives light only from the right-eye image, and the other phototube only from the left-eye image.

The signal from each phototube is amplified separately by a circuit that provides a 1-msec pulse at the beginning of the projection of the first frame of a new scene. There are thus obtained two brief pulses, each of which represents the beginning of a new scene in one of the films. If these two pulses occur simultaneously, the synchronism is perfect, and the meter reads zero. If, however, the pulses do not occur simultaneously, the interval between them is measured by a special timing circuit and the result — the synchronization error — is displayed on the meter. Simply by looking at the meter the projectionist sees which film is ahead and by how much.

Polaroid 3-D Sync Monitor, Model E

More recently, a much less expensive type of 3-D synchronization monitor has been developed, which offers almost equally good performance provided the projectionist familiarizes himself with its use, and provided slightly modified projector shutter blades are used (Fig. 2).

The Model E device, operating on a stroboscopic principle, consists essentially of a slotted disk rotated at 60 rpm by a Telechron motor. A window is provided so that one can look through a portion of the slotted disk, and a split-field polarizer is placed over the window. The upper half of the field passes the right-eye image and the lower half passes the left-eye image.

Looking into the window, the projectionist sees two sets of stripes, each of which corresponds to $\frac{1}{48}$ sec, or $\frac{1}{2}$ frame. Thanks to the special modification of the projector shutter blades (slot made in the cutoff blade), every other stripe appears fluted, as shown in Fig. 3. If the stripe pattern appears as in Fig. 3, i.e., with the upper stripes not quite aligned with the lower stripes, the synchronism is imperfect.

Perfect synchronism appears as in Fig. 4. Unfortunately, this same pattern results if the synchronization is incorrect by an amount which is large and equals exactly one frame, or exactly two frames, or exactly any number of whole frames. Thus the projectionist must be qualified to distinguish perfect from grossly incorrect synchronism.

In using the Model E Sync Control,

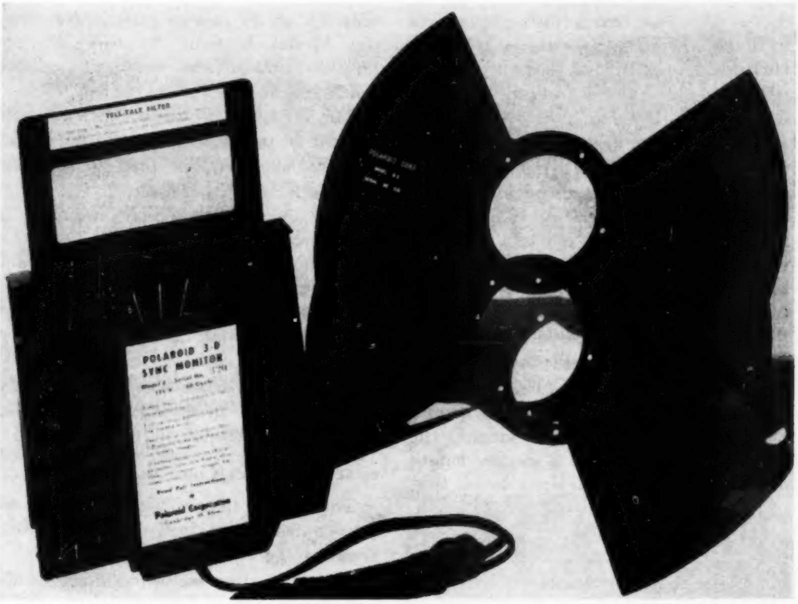


Fig. 2. Showing the Polaroid 3-D Sync Monitor, Model E, with the Tell-Tale Filter. The photograph shows also two of the slotted shutters that are suitable for Simplex Standard and Super Projectors.

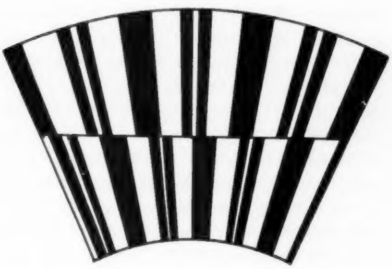


Fig. 3. Showing the appearance of the window in the Model E Sync Monitor when the left projector is leading by ⅜ frame. The white line down the middle of alternate stripes is due to the slot in the cutoff blade of the shutter.

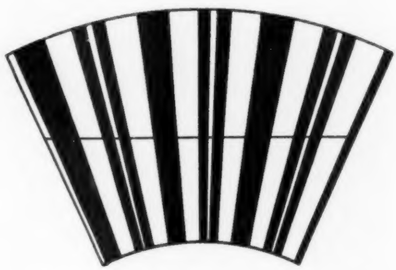


Fig. 4. Showing the appearance of the window in the Model E Sync Monitor when the synchronism is perfect. Note that the stripes above and below are perfectly lined up. This appearance in the Model E Monitor does not prove that the synchronism is perfect, however, but that it is either perfect, or imperfect by one or more complete frames.

the projectionist first adjusts the control so that the window appears as in Fig. 4. He then knows that the synchronism is perfect, or is imperfect by one or more full frames. He then puts on a pair of 3-D viewers, and looks at the screen. If fast moving objects have a clean, solid, sharp appearance, he knows that the synchronism is perfect. If, however, fast moving objects have a blurred, watery, transparent appearance, he knows that the synchronism is imperfect by one or more whole frames.

To correct imperfect synchronism, the projectionist changes the synchronization, *one full frame at a time*, and notes whether the watery appearance gets better or worse. By this means, the projectionist is able, in a shorter length of time than it takes to describe all this, to obtain perfect synchronism.

During the first showing of a new film, the projectionist should recheck the synchronism at frequent intervals to guard against the occurrence of a mismatched splice.

If the synchronization is in error by as much as two or three frames or more, the projectionist easily detects double-imagery in scenes containing fast action; for example, when a man raises his arm quickly, two arms appear to rise. When the synchronization error is as large as this, the *direction* of the error can be determined by a special Tell-Tale Filter mounted on the top of the Monitor. Seen through this filter, the right-eye pictures appear red and the left-eye pictures appear green. Suppose now a light-colored object, such as a hand, suddenly moves rapidly. If the red image begins to move first and moves ahead, it is evident that the right projector is leading, and conversely. Thus even when very large errors in synchronization occur, the projectionist readily finds what corrective action to take.

All this sounds complicated. But once the projectionist becomes familiar with the instrument (and this takes only 15 or 20 min of experimentation) the Model E Sync Monitor permits him to obtain and maintain perfect synchronism quickly and easily.

The modified projector shutter blades present no problem since a suitable pair, already modified, is usually supplied with each Model E Monitor.

The question: Which monitor is recommended? is easily answered. An ideal monitoring installation would include both the Model 21 and the Model E. However, in those applications where only a small outlay can be made, the Model E device should perform very well. Both devices have already been tried out in several theaters, and perform as intended.

Synchronization Controls

The basic purpose of a synchronization control is to adjust the synchronism between the two projectors.

Every synchronization control, however much disguised, is the equivalent of a mechanical differential. In fact, a mechanical differential is exactly what one needs to control the synchronization when mechanical interlocks are employed. In the type of mechanical interlock that employs a flexible cable, a gearbox is present in the middle of the cable. To obtain differential control, all that one needs to do is to mount the gearbox so that it can be rotated as a whole. One half revolution of the gearbox changes the synchronism by one frame if the cable rotates at 1440 rpm. We have constructed several differential controls of this type, and they are operating very well in the Boston theaters where they are installed.

Most theaters, however, employ electrical interlocks. They use General Electric Selsyns, or synchros of other manufacturers. In such installations the straightforward method of controlling synchronism is to use a differential generator. We have also developed a rotary six-position electrical switch that performs the same function.

Differential Generators

A differential generator is a special type of electric motor. It has a three-pole delta-connected rotor, and a three-pole delta-connected stator. The rotor is connected to the three-wire secondary of the synchro of one projector, and the stator is similarly connected to the secondary of the synchro of the other projector. When so connected, the synchronism of the two projectors can be controlled by rotating the shaft of the differential generator. If the synchros rotate at 1440 rpm, one revolution of the differential generator changes the synchronism by one frame.

The differential generator must be matched to the secondary voltage and the power frequency of the synchros. If, for example, General Electric 2JA33 or 2JA39 Selsyns are used, the General Electric 5MJ35CB Differential Selsyn should be employed.

We have modified a number of differential generators of both Stancil-Hoffman and General Electric manufacture, by fitting them with control knobs, and locks. One of these is shown in Fig. 5. In order to control the synchronism, one simply loosens the lock and turns the wheel slowly. One clockwise rotation of the control knob advances the right projector exactly one frame in 1440 rpm installations. After the adjustment is made, the lock is retightened (In installations where the synchros rotate at 1200 rpm, $\frac{5}{6}$ turn of the control knob changes the synchronism by exactly one frame.) Thus any synchronization error, large or small, is easily corrected.

The differential generator is probably the best method of synchronization control with electrical interlocks. It has the disadvantage, however, that a different type of differential generator must be employed for each type of synchro. Furthermore, it has the disadvantage of relatively high cost: about $280.00.

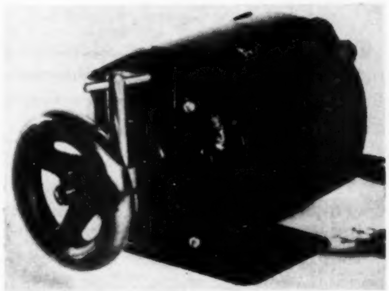


Fig. 5. Showing the General Electric Differential Selsyn 5MJ35CB1A (110 v, 60 cps) with a control wheel and brake added.

Fig. 6. Showing the Polaroid 3-D Sync Control, Model S-3. Six steps of the control (one complete rotation of the control knob) changes the synchronization by one frame. This Sync Control contains a rotary 5-pole 6-position motor-control switch of 10 amp continuous rating at 110 v, made by the Electro Switch Co.

Polaroid 3-D Sync Control, Model S-3

The primary purpose in developing the Model S-3 Sync Control shown in Fig. 6 was to provide an inexpensive substitute for a differential generator. It has turned out that the Model S-3 is very little inferior to a differential generator, and indeed, has some advantages over it.

Electrically, the Model S-3 is a 6-position rotary switch. The switch proper is a 5-pole, 6-position switch of the break-before-make type. The 35 terminals of the switch are wired to a 10-wire terminal strip. All external connections are made to the 10 contacts of the terminal strip.

The Model S-3 can be used only with single-phase synchros, of the usual (5-wire) type. It cannot be used with 3-phase synchros (6-wire) type. Except for this limitation (of very little practical importance), it can be used with synchros of any manufacture, of any secondary voltage, and with any power frequency.

When the switch is snapped from one position to the next, two functions are accomplished: (1) The primary connection of one of the synchros is reversed, causing a 180° rotation of the equilibrium position. (2) The connection between the 3-wire secondaries of the two synchros is cyclically permuted, causing a 120° rotation of the equilibrium position. The net effect is that each step of the control causes a 60° change in the equilibrium position of one synchro (and one projector) with respect to the other. Each step of the Control thus changes the synchronism by $\frac{1}{6}$ frame in 1440-rpm systems, or $\frac{1}{5}$ frame in 1200-rpm systems.

Because the Control provides a discontinuous adjustment of the synchronism, with steps of $\frac{1}{6}$ frame, it is not possible to obtain exactly perfect synchronism. It is always possible, however, to come within $\frac{1}{12}$ frame of perfect synchronism; this is three times better than is required by critical observers, and thus may be called perfect for all practical purposes.

The S-3 Control has the advantage that one does not have to look at the control knob to see how far it has been turned. By counting the steps mentally, one can look continuously at the window of the Model E Monitor while one is turning the knob of the Control. Also, no unlocking and locking operations are involved.

Finally, the Model S-3 Sync Control has the important advantage of low cost: about one tenth that of the differential generator.

Both the differential generator and the Model S-3 Sync Control can be used with entire success in installations which include stereophonic sound systems.

Conclusion

In summary, Polaroid has developed equipment that makes it possible to achieve and maintain perfect synchronism in the presentation of two-film 3-D motion pictures. The Model 21 Electronic Sync Monitor accomplishes this function in a manner that leaves little to be desired in the way of simplicity of performance. The Model E Sync Monitor accomplishes the same function very inexpensively, at the cost, however, of installing Modified Shutter Blades in the two projectors and of requiring a small amount of self-training on the part of the projectionist.

With the exception of the differential generators, all of the instruments described were developed from the ground up by scientists in the Research Laboratory of Polaroid Corporation. It is a pleasure to acknowledge the important contributions made by Messrs A. G. Carpenter, L. W. Chubb, J. A. De-Young, J. C. Gray, D. S. Grey, Dr. C. H. Matz and M. Parrish, Jr.

Discussion

George Lewin (*Signal Corps Pictorial Center*): Is there a chance that the Model 21 would be affected if the illumination of

one projector is much different from the other?

Dr. Jones: No, the two electrical channels, one for each eye, have independent AGC (automatic gain control) circuits. There can be a 10 to 1 difference between the two in practice and the equipment is in no way affected in its accuracy.

Mr. Lewin: Then, when you make the adjustment with the step control, do you have to wait for the next scene change to know whether you've gone in the right direction?

Dr. Jones: This is a complicated situation. First of all, you know quantitatively from the instrument how much of a correction to make and in which direction to make it. So usually on your first effort you have successfully corrected the sync error and you merely wait for the confirmation of the indicator that the error is zero. If, however, one wishes to follow the change as it is made, one uses the Model E device simultaneously and follows the change in sync as the correction is made with the sync-control switch. In fact, the ideal installation has both kinds of Sync Monitors.

Mr. Lewin: Is it possible that on certain scene changes there isn't enough change in density to give you an indication?

Dr. Jones: I'd say offhand that we get about three-quarters of all the scene changes

Mr. Lewin: In other words, you might be fooled sometimes if the change in density isn't sufficient from scene to scene. You might think that you're in sync, but actually be out.

Dr. Jones: There is a light on the meter case that flashes if, and only if, a new reading is obtained. Thus you always know when another reading is obtained. Furthermore, the meter holds the last reading. Thus if you have made a change in the sync since the last reading, you expect that the meter reading will change when the next reading is obtained. Accordingly, I see no possibility of confusion in using the instrument. Alternatively, by throwing a switch, a gong inside the chassis is connected that rings if, and only if, a new reading is obtained.

Vidicon for Film Pickup

By R. G. NEUHAUSER

This paper discusses the use of a vidicon camera tube for film pickup and describes special operating techniques for obtaining best performance. The operating principles of the vidicon are reviewed briefly and performance characteristics are given. Basic features desired for satisfactory reproduction of film on television are discussed, including high signal-to-noise ratio, "built-in" gamma of the proper magnitude, accurate black-level reproduction, excellent resolution, and freedom from spurious signals.

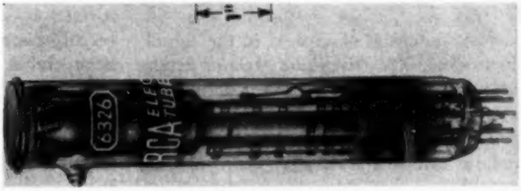
One might well wonder how a tube as small as the vidicon[1] can be made to produce a picture from film pickup equal or even superior to that produced by a broadcast-quality image orthicon or iconoscope. In view of the high picture quality needed for broadcast work, a pessimistic appraisal of the vidicon's performance would be justified — if the tube were operated in a conventional manner. However, by recognizing and applying some of the basic characteristics of the vidicon, and by the use of two special operating techniques, this small and relatively simple tube can be made to outperform present film-reproducing types, not only from the standpoint of picture quality, but in simplicity of associated equipment and operation.

The tube to be described in this paper is the recently introduced RCA-6326 film-camera vidicon. The useful performance characteristics of the RCA-6326 and the special operating techniques developed for its application to broadcast film pickup will be considered in detail. First, however, the operating principles of the vidicon will be reviewed to show how the signal is generated and to point out how these operating principles affect the performance of the tube in film-pickup systems.

Presented on October 7, 1953, at the Society's Convention at New York by R. G. Neuhauser, Radio Corporation of America, Tube Dept., Lancaster, Pa.
(This paper was first received November 24, 1953, and in revised form January 4, 1954.)

Vidicon Construction

Figure 1 shows a cross section of the RCA-6326 vidicon and its associated components. On the inside of the faceplate are a signal electrode and a photoconductive layer. The signal electrode is a transparent, electrically conductive coating. External connection to the signal electrode is made through the flanged metal ring that forms the intermediate seal between the faceplate and the bulb wall. Deposited directly on this signal electrode is the photoconductive layer. This layer is a rather good insulator in the dark and has the



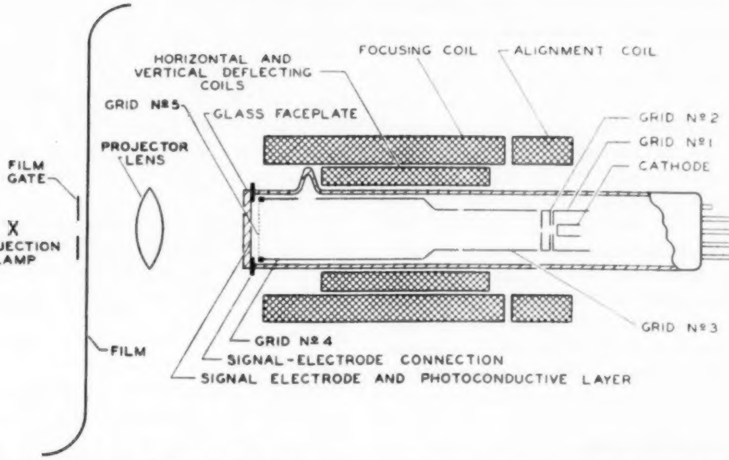


Fig. 1. Above: the RCA-6326 vidicon for film-pickup applications. Below: a cross section of the 6326 vidicon and its associated components.

characteristic of decreasing in resistivity when illuminated.

Directly behind the photoconductive layer is a fine-mesh screen (grid No. 5), which maintains a uniform decelerating field for the scanning beam supplied by the electron gun near the base of the tube. Behind grid No. 5 and connected to its periphery is a cylindrical electrode (grid No. 4). The scanning electron beam is brought to a sharp focus on the gun side of the photoconductive layer by the axial magnetic field of the external focusing coil and the electrostatic fields of grid No. 4 and grid No. 5, in much the same manner as in the image orthicon, but with only one loop of focus. Grid No. 3 is a separate electrode introduced for the purpose of applying a "dynamic focusing" voltage, if desired, to compensate for a slight degradation of focus in the corners of the picture. If "dynamic focusing" is not required, grid No. 3 is connected externally to grids No. 4 and No. 5. Scanning is accomplished by magnetic deflecting coils that are placed directly adjacent to the tube and inside the focusing coil. The alignment coil located at the rear of the focusing coil is necessary to align the electron beam with respect to the magnetic focusing field.

Vidicon Operation

Figure 2 illustrates the manner in which the vidicon generates a video signal from the optical image. The tube uses the same principle of low-velocity scanning as the image orthicon.

In this method of operation a small positive potential is applied to the signal electrode. The scanning beam lands on the surface of the photoconductive layer at vertical incidence and with nearly zero velocity, and drives the surface under the beam down to the potential of the thermionic cathode of the electron gun. The signal-electrode assembly and photoconductive layer form slightly leaky capacitors across which the signal-electrode voltage is impressed. The light from the scene to be televised is focused on the plane of the photoconductive surface and lowers its resistivity at each point in proportion to the light intensity at that point. In the interval between successive scans of any one picture element, each point on the beam side of the photosurface will charge up toward the signal-electrode potential through the leakage path set up by this change in conductivity. The photoconductive surface is so thin with respect to the picture-element size that there is no appreciable lateral leakage of this charge. Therefore, in the interval between scans, a charge pattern that corresponds to the illumination at each point is built up on the beam side of the photoconductive layer. The scanning beam deposits a sufficient number of electrons on this surface to drive the surface back down to cathode potential. A corresponding number of electrons flows out of the signal electrode and develops a video signal across the load resistor. The signal voltage across this resistor is coupled to the video preamplifier.

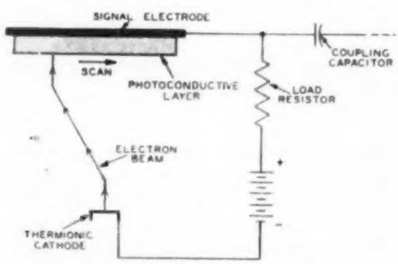


Fig. 2. Diagram of the vidicon principle. Illumination of the signal electrode by the projected film image produces a corresponding pattern of positive charges on the beam side of the photoconductive layer. These charges are reduced to cathode potential on each vertical sweep by electrons collected from the scanning beam. The resulting variations in signal-electrode constitute the video signal. No secondary-emission phenomena are involved due to the fact that the beam lands on the photosurface at practically zero velocity.

The following is a description of the performance characteristics of the 6326 vidicon and the significance of these characteristics in film-pickup applications.

Resolution

Resolution is one of the most important items to be considered when determining the usefulness of a camera tube for television broadcast work. In order to adhere to television terminology, we will refer to the resolving characteristics of the vidicon in terms of television line numbers and the horizontal amplitude response at a given line number. The horizontal amplitude response will be defined as the peak-to-peak signal response to a square-wave test pattern.

In determining the merit of any pickup device it is not sufficient merely to determine its limiting resolution, although in general, the device that has the highest value of limiting resolution will produce the sharpest picture. The film-pickup vidicon, if properly operated, will invariably show a limiting resolution in excess of 700 lines. However, limiting resolution alone has relatively little significance as a yardstick for evaluating the performance of the vidicon in a film-pickup system because the additional picture information available at the 700-lines point represents as

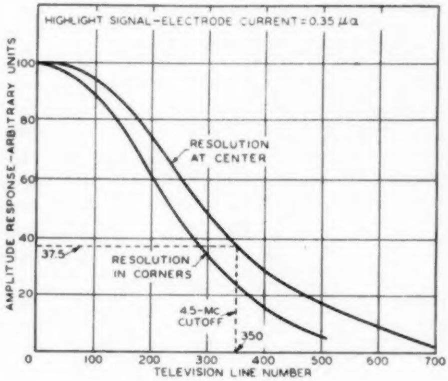


Fig. 3. Amplitude response (horizontal resolution) of the 6326 vidicon as a function of television line number. The slight loss in corner response can be corrected by the application of a "dynamic focusing" voltage to grid No. 3, as described in the text.

little as 2% of the total peak signal. The important characteristic of the vidicon is its amplitude response, which is shown in Fig. 3. A significant point on the curve is that for 350 lines, corresponding to the 4.5-mc cutoff frequency of the television broadcast video signal. The amplitude response at this point is 37.5% of the black-to-white signal at lower line numbers. This figure represents the resolution at the center of the tube. There is some degradation of the focus, and consequently of the resolution as the measurements are taken toward the corners of the raster. The corner response of the tube is also shown in Fig. 3.

Unlike the image orthicon or the iconoscope, the resolution of the vidicon is not affected by anything other than the dimensions and shape of the scanning beam itself. Since this is the case, high beam currents, which widen the spread of the beam considerably, will reduce the resolving capability. The measurements of amplitude response represented by Fig. 3 were taken with what is considered a desirable maximum-highlight signal-electrode current between 0.3 and 0.4 μa. An attempt to obtain greater highlight-signal output would require an increase in beam current and rapidly reduce the amplitude response of the tube.

Signal-to-Noise Ratio

The high signal-to-noise ratio of the vidicon video signal is perhaps its next most significant feature, because its high value allows the application of techniques that produce a picture of superior quality. Even when limited to between 0.3 and 0.4 μa, as previously noted, the highlight signal-electrode current of the film-pickup vidicon is approximately three times the peak signal available from the iconoscope generally used for film-pickup work. The visual equivalent signal-to-noise ratio* of the signal developed by the vidicon has been measured as 300 to 1. This figure, however, depends on the type of preamplifier used, since the vidicon itself contributes no appreciable noise to the video signal. The preamplifier recommended for this tube is a cascode type employing low-noise, high-transconductance triodes, similar to the preamplifiers used with iconoscope equipment. This feature of low noise in the video signal is of the utmost importance because it permits aperture correction to be used to best advantage.

Aperture Correction

The use of aperture correction is one of the special operating techniques

* Defined in the Appendix.

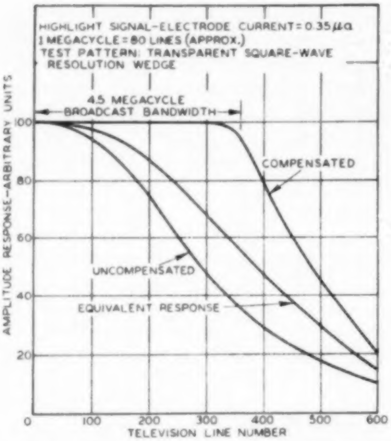


Fig. 4. Improved horizontal resolution (compensated curve) obtained by applying aperture correction to the output of the 6326 vidicon. The curve labeled "Equivalent Response" represents the geometric mean of the horizontal and vertical resolutions after aperture correction.

mentioned previously which enable the vidicon to produce superior performance. Aperture correction is the process of compensating for the drop-off in amplitude response shown in Fig. 3. Correction for this drop-off is accomplished by boosting the high-frequency response of the video amplifier in such a manner that the amplitude response curve is linear up to some predetermined cutoff frequency and compensating for the phase shift introduced in the frequency-response boosting process.[2] The vidicon is the first camera tube to develop a high enough signal-to-noise ratio to allow effective use of aperture correction. The application of aperture correction does not increase the *limiting resolution* of the vidicon, but it does make it possible to boost the *horizontal resolution* to 100% over the entire transmitted bandwidth as shown in Fig. 4.

The role which the high signal-to-noise ratio of the vidicon signal plays in aperture correction is as follows: The noise energy in the signal from the vidicon camera is contributed principally by the first amplifier stage. This type of noise is proportional to frequency, with the result that nearly all the noise energy in the video signal is concentrated in the higher frequencies. Boosting the signal information at the higher frequencies does not increase the overall signal amplitude, but it does boost the noise, with the result that the signal-to-noise ratio decreases almost directly as the amount of boost increases. A maximum boost of approximately 3 to 1 at the 350-lines point will reduce the signal-to-noise ratio of the picture to approximately 100 to 1, which is still a very satisfactory value.

It should be noted that this type of aperture correction does not boost the vertical resolution of the vidicon tube. The resulting equivalent amplitude response of the vidicon tube output signal is therefore a combination of the vertical and the horizontal amplitude responses. The resulting equivalent response is shown in Fig. 4. This curve is the square root of the product of the uncompensated and the compensated curves, and represents the overall performance of the tube with aperture correction of 3 to 1 at the cutoff frequency of 4.5 mc. The resulting signal-to-noise ratio is still higher than that of any camera tube or film-pickup system in current use.

Signal-Electrode Voltage

We have seen how the high signal-to-noise ratio of the vidicon can be used to improve its resolving capabilities. The second operating technique which clears up the remaining possible objections to the vidicon as a film-camera tube is the use of a signal-electrode voltage considerably lower than the value recommended for maximum sensitivity.

The use of reduced values of signal-electrode voltage for the vidicon improves

its performance in two ways. The first and most pronounced improvement is a reduction in dark current. It will be remembered that the photoconductive layer is a rather good insulator in the dark. However, there is always some current flow through the material even in total darkness. A uniform dark current would not be objectionable but variations in the dark current over the useful area of the photoconductive layer are highly undesirable. This dark-current variation, if too prominent, will be exhibited as a flare signal, not unlike the signal from an iconoscope in the dark. It is logical to assume that if the average value of the dark current is reduced, the amplitudes of variations of the dark current will be reduced. Operation of the signal electrode at lower than normal voltage reduces the dark current to a very small value and, as a result, the dark-current flare in the picture is reduced to an imperceptible level. The sensitivity of the photosurface also decreases with this reduction in signal-electrode voltage, although not as rapidly as the dark current. This is illustrated by Fig. 5, which shows the ratio of signal current to dark current at various signal-electrode voltages, under constant illumination. However, for film-pickup applications this loss of sensitivity is a minor problem, since the vidicon has very high inherent sensitivity and the illumination needed for its small photosurface area is low.

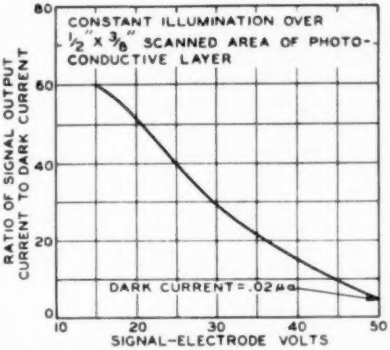


Fig. 5. Ratio of signal-output current to dark current in the 6326 vidicon at various signal-electrode voltages.

Signal Lag

Reduction of the applied signal-electrode voltage improved the performance of the vidicon in still another manner. One of the characteristics of the photoconductive surface used in the vidicon is a lag in its response to changing illumination. This produces a slight smearing of moving objects in normal operation. However, a reduction of the applied signal-electrode voltage and the resulting necessary increase in light on the photosurface considerably reduces the lag of the vidicon signal. The yardstick that has been adopted to measure or rate the lag is the amount of residual signal developed by the tube after 1/20 sec in the dark, which is slightly longer than the time necessary to discharge a complete frame. Figure 6 shows the lag of the vidicon signal at various signal-electrode voltages. It can be seen from this curve that the lag drops almost directly with the signal-electrode voltage. When operated at 25 v (one-half normal signal-electrode voltage), the residual signal after 1/20 sec is down to only slightly more than 10%, or less than half its normal value. By way of comparison, this is very close to the lag characteristic of an image orthicon operated at full storage. At this operating point, the lag of the signal produced by the vidicon is entirely unobjectionable in film reproduction.

Vidicon Gamma

The vidicon has several other very desirable characteristics that present no problems and require no special operating techniques. Perhaps the most important of these is its light-transfer characteristic.

If the light-transfer characteristic of a transducer such as a camera tube

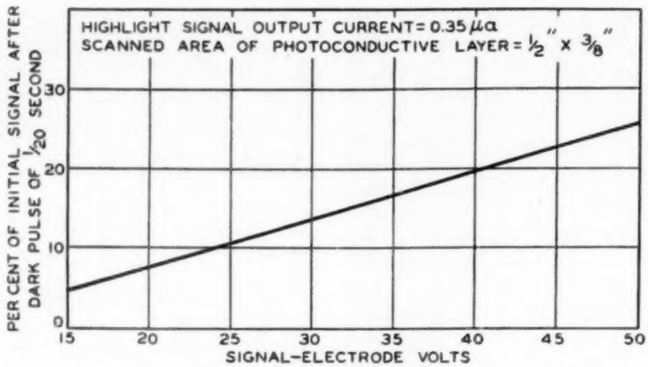


Fig. 6. Relative "lag" of the vidicon signal as a function of signal-electrode voltage.

follows closely a simple power law, we can refer to the slope of the transfer characteristic on a *log-lot plot* as the "gamma" of the device. The curves of Fig. 7 show that the gamma of the vidicon is essentially constant at 0.65 over the entire range of signal-electrode voltages given. This is almost exactly the desired gamma characteristic needed to match positive motion-picture film to a kinescope transfer characteristic. The overall transfer characteristic of such a system is slightly above unity gamma, which corresponds closely to current television-studio practice.

The photoconductive surface of a vidicon produces a very accurate and precise reproduction of a picture. Unlike other camera tubes it is not troubled by edging effects, electron redistribution, or flare, nor does the vidicon picture show any grain structure due to the

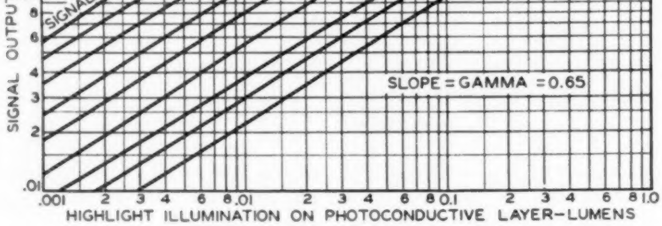


Fig. 7. Transfer characteristics of the 6326 vidicon at various signal-electrode voltages.

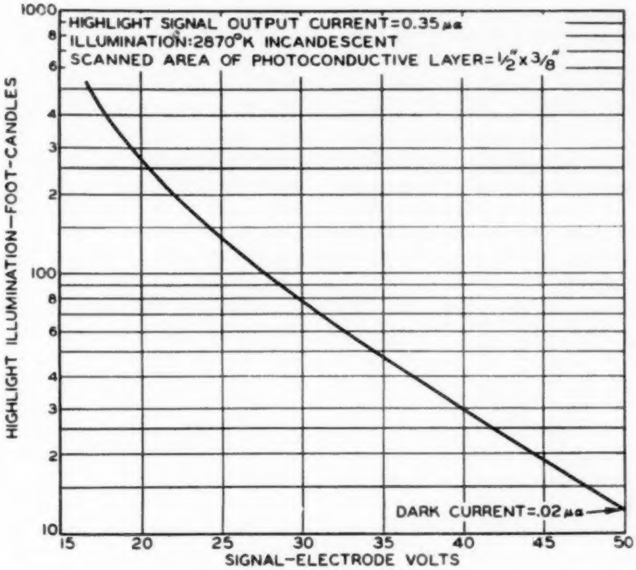


Fig. 8. Illumination requirements of the vidicon photosurface for a highlight-signal current of 0.35 μa.

fact that the photoconductive layer has a continuous surface. The constant gamma of the surface acts to reproduce each portion of the scene in its true tone values regardless of the illumination of adjacent areas or the overall illumination level. For this reason, the camera needs no white- or black-stretching circuits to produce a picture with accurate tone rendition. The gamma of 0.65 also allows the tube to generate a picture with a very high contrast range. A dynamic contrast range of 200 to 1 can be reproduced.

Black Level

Another desirable characteristic of the vidicon is its ability to furnish accurate black-level information in the video signal. With operation at low signal-electrode voltages, true blacks in the scene represent essentially zero current from the signal electrode. The signal during the scanning retrace also represents zero output current, since the scanning beam is prevented from landing during this time by the application of a blanking pulse to the electron gun. Blanking is accomplished either by applying a negative blanking pulse to the control grid of sufficient amplitude to cut the beam off completely or by the application of a positive pulse to the cathode. The positive pulse applied to the cathode need only be of sufficient amplitude to prevent the beam from landing on the photoconductive surface which has been driven to zero potential during the scanning interval. The signal level obtained during the retrace is used by the camera clamp circuits to set the black level of the video signal (sometimes called the "d-c component").

Light Requirements

The curve of Fig. 8 indicates the order of magnitude of illumination required

on the photosurface to produce the recommended 0.35-μa value of highlight-signal current. It shows that the light required varies almost inversely with the cube of the signal-electrode voltage. In terms of foot-candles these figures may seem rather high, but actually only $\frac{3}{8}$ lm is needed to produce approximately 250 ft-c of illumination on the photosurface because the useful photo-area of the vidicon is only 0.875 sq in. ($\frac{1}{2} \times \frac{3}{8}$ in.).

Experience in operating the new vidicon in film cameras has shown that the optimum value of light on the photosurface is an average illumination of about 250 ft-c. Since there is some difference in sensitivity between individual film-pickup vidicons operated at a given signal-electrode voltage, the fixed parameter of a system will be the light level used, with the signal-electrode voltage adjusted to produce the proper output-signal level. The signal-electrode operating potential at this point will lie between 15 and 25 v, which is slightly less than half the voltage that would be used if maximum sensitivity were the only requirement.

Other Characteristics

The spectral sensitivity of the photoconductive layer used in the RCA-6326 vidicon is essentially panchromatic. It follows closely the spectral response of the image orthicon, having its lowest sensitivity in the red regions and practically no infrared response. This makes the vidicon highly suitable for the reproduction of color film on a monochrome system. The low infrared response of the tube makes an infrared filter in the optical system unnecessary from this standpoint, although such a filter may be required to reduce heating of the photoconductive layer at high illumination levels. Image storage on the vidicon presents no problem at all for motion-picture work. The storage characteristics are excellent. The length of time that an image can be stored on the photosurface without loss of amplitude or resolution is at least several seconds.

The vidicon can operate with any television film projector which has a 3–2 "pulldown ratio" or light-application rate. (In this type of projector the standard film speed of 24 frames/sec is converted to the 60-field/sec rate required for television by the use of a special shutter or pulsed light source which project five images of equal duration over each interval of 1/12 sec. The pulldown mechanism or drive holds successive frames of the film in the light gate for unequal lengths of time, so that the first frame of each pair is illuminated by three light pulses and the second by two.) In addition to this, one attractive feature of the vidicon is its ability to suppress the effect of the light-application bar of the film projector. If the light-application time is in the order of 30% of the active scanning time for a single television field, the light-application bar will be entirely unnoticeable. This is a very desirable characteristic because the projector meeting this requirement need not be synchronized with the field repetition rate of the television signal when used with the vidicon film camera. The tube will not operate satisfactorily in a system that does not have a projector with a 3–2 pulldown ratio or light-application rate because of the low-frequency flicker resulting from variations in the illumination of successive frames.

Exhaustive data on the life of the film-pickup vidicon have not been accumulated at this time due to the fact that the tube has only recently been made available for commercial use. However, indications are that it will be possible to obtain life in excess of 1000 hours in film-camera operation.

Conclusion

The behavior of the RCA-6326 film-pickup vidicon shows that this tube has all the basic performance character-

istics desired for television broadcast use. Its outstanding features are high signal-to-noise ratio, "built-in" gamma of the proper magnitude, accurate black-level reproduction, excellent resolution, and freedom from spurious signals. The tube is also outstanding in its ease of operation and usefulness for nonsynchronous operation. It is felt that the new vidicon provides the best solution to date for the problem of film reproduction on television.

Acknowledgments

Acknowledgments are due to Robert B. Toppmeyer and F. David Marschka of the RCA Tube Dept., Lancaster, Pa., for assisting in the evaluation of the performance and quality characteristics of the vidicon for this application; and to B. H. Vine, also of the RCA Tube Dept., who did most of the basic design work on the tube and suggested a number of the operating procedures. H. N. Kozanowski and E. M. Gore of the RCA Engineering Products Dept., Camden, N.J., have also contributed much valuable information based on their work in developing a film-camera chain for the 6326 vidicon.

APPENDIX

Horizontal Amplitude Response: In this paper this term represents the measured peak-to-peak signal developed from a square-wave test pattern resolution wedge. This type of test is used more than any other for evaluating the resolving capabilities of a camera tube.

Equivalent Amplitude Response: This is the geometric mean of the horizontal resolution and the vertical resolution (both expressed in numbers of picture lines). It is expressed as $R_{eq} = \sqrt{R_v \times R_h}$ where R_v and R_h are the vertical and horizontal resolutions, respectively.

Signal-to-Noise Ratio: The term "visual equivalent signal-to-noise ratio" has been coined for this presentation. Since the vidicon signal is applied to a peaked amplifier, the noise of the camera video signal is concentrated at the high end of the transmitted band. This high-frequency noise is not as apparent to the eye as the lower-frequency noise components. As a result, for a 4.5-mc bandwidth the peak signal-to-rms noise ratio can be multiplied by a factor of approximately three to obtain the visual equivalent signal-to-noise ratio.[2] This is not true, however, of the image orthicon, which produces so-called "flat noise" having equal energy distribution throughout the bandwidth.

Gamma: This property of the transfer characteristic of a transducer such as a camera tube is obtained from the equation

$$I_s = E_i^{\gamma}$$

where I_s is the signal output,
E_i is the incident illumination, and
γ, or gamma, is the exponent.

References

1. B. H. Vine, R. B. Janes, and F. S. Veith, "Performance of the vidicon, a developmental camera tube," *RCA Rev., 13, No. 1:* Mar. 1952.
2. O. H. Schade, "Electro-optical characteristics of television systems, Part III," *RCA Rev., 9, No. 3:* Sept. 1948.

Discussion

James H. Ramsay (Philco Corp.): Is there another vidicon tube different from this one?

Mr. Neuhauser: There is a vidicon tube that was developed for the industrial market. That is the 6198, from which this one, the 6326, has actually evolved. The 6326 has a different gun structure and it is processed differently.

Mr. Ramsay: Could you go into much detail on the differences between the two?

Mr. Neuhauser: The differences are mostly in the gun structure and in the care and testing and processing, as well as in the quality limits.

Mr. Ramsay: The previous one, the 6198, did not have the dynamic focusing on it?

Mr. Neuhauser: That's correct. There was no dynamic-focusing electrode in the 6198. There is in this tube.

Mr. Ramsay: Also, could you explain what causes the good signal-to-noise ratio of this tube?

Mr. Neuhauser: The good signal-to-noise ratio is produced merely by the fact that you can get a high signal out of the tube. It produces about three to four times the signal that you get out of an iconoscope operated at 0.1-μa beam current, which is the value we recommend for the iconoscope.

Mr. Ramsay: Would not the signal-to-noise ratio of the iconoscope be equally as good if operated at the same illumination as is recommended for the vidicon?

Mr. Neuhauser: Not unless the beam current of the iconoscope were increased above the recommended value of 0.1 μa. Such an increase in beam current unfortunately produces uncontrollable flare or background variations as the result of excess secondary electrons falling back on the mosaic of the iconoscope.

Frank N. Gillette (General Precision Laboratory): You mentioned that the vidicon performed recently with shutter impulses of as little as 30% illumination duty cycle. Other workers in that field have reported the necessity of a taper on the rise and fall of the light beam when the duty cycle is as low as 30%. Do you confirm that result?

Mr. Neuhauser: I have a projector that has about a 25% application time square application pulse and I have not been aware of any application bar. As viewing gets more critical you may find that there has to be a tapered-light application. At present I would say it does not require a tapered shutter or a graded shutter.

Mr. Ramsay: You gave a figure on the number of seconds for storage time on this tube. Would that figure also hold for the 6198?

Mr. Neuhauser: I think it would, yes.

Mr. Ramsay: And that is storage time for an unscanned tube?

Mr. Neuhauser: Yes.

Vidicon Film-Reproduction Cameras

By HENRY N. KOZANOWSKI

Analysis and experience show that an ideal device for television film reproduction should have high resolution, excellent signal-to-noise ratio, wide contrast range, a stable gamma characteristic with a slope of 0.6 and good black-level control. It should operate with standard television projectors. Our work during the past two years has convinced us that the vidicon camera comes closest to this ideal. In addition to the characteristics already mentioned, the vidicon camera can be operated nonsynchronously, making it possible to provide local film inserts in network programming. The sensitivity for film operation is approximately three times greater than with the iconoscope, providing a large increase in projector lamp life. The simplicity and stability of a vidicon camera system make it very attractive for "unattended" operation with a minimum of adjustment and attention.

A particular form of vidicon film camera with its deflection, video and control circuits is described and illustrated. The problems and possible solutions of optical and electrical multiplexing for typical television broadcast operation are discussed. A broadcasting requirement for the reproduction of transparencies, opaques and other more specialized opaque presentations can be filled by equipment which is now in a product-development phase. We believe that, with the developments now available, the television broadcaster can provide picture quality in this field comparable with the best live pickup performance with equipment requiring only nominal attention and skill.

SINCE THE earliest days of television, both in its experimental phases and in commercial television broadcasting, the problem of reproducing motion-picture film has received concentrated and continued attention. Motion-picture film originally offered a wide choice of readily available program material as compared to the production of live-studio shows which require more elaborate facilities, long rehearsal time and considerably greater expense. With the development of better studio pickup cameras, such as those based on the image-orthicon tube, it became possible to produce high-quality studio programs

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with relatively modest lighting requirements. Under these conditions, it was apparent that improvements were required in the film system to bring it up to the new standards of studio quality. The iconoscope camera, which has been almost universally used for film reproduction, was re-examined thoroughly and many improvements were made in circuits and operating techniques.[1] These improvements have resulted in a substantial gain in picture quality and have been widely introduced into current film-reproducing equipment in television broadcasting stations. With high-quality film and careful operating techniques, the pictures compare favorably with those which originate in studios.

However, within the last few years, there has been a definite trend in the direction of recording certain programs directly on film for reasons of smoother performance, possibilities of editing, less strain on actors and the increased versatility provided by the application of well-developed motion-picture techniques. Such a program is, therefore, no longer considered as a substitute for live-studio programs, but as a direct competitor. In this case, the ultimate goal is picture quality which will make it impossible for the home television viewer to know whether the program material is live or has been recorded on film. The same goal is called for in kinescope photography for delayed broadcast, program storage and distribution by network-affiliated stations. The formation of these new trends in television broadcasting spurred on an intensive program of evaluating many incompletely explored methods of film reproduction. Investigations showed that the vidicon pickup tube offers the greatest possibility for realizing these new objectives. Our work on the Vidicon Film Camera during the past two years has convinced us that it comes closest to meeting the requirements for an ideal film camera.

Performance Requirements for a Television Film Camera

Before describing the vidicon camera, it may be of interest to tabulate the main factors in any television reproducing system which are the criteria for good performance. These are:

A. Resolution or aperture response.
B. Available signal-to-noise ratio.
C. Possibility of aperture-response correction.
D. Gray-scale or transfer characteristic.
E. Film-reproduction range and film latitude.
F. Light-source requirements.
G. Effect of spurious signals or shading.
H. Black-level reference.
I. Nonsynchronous projector operation.
J. Possibilities for unattended operation.

The vidicon tube was invented at RCA Laboratories[2] and developed into a commercial product at the RCA Victor Tube Development Group at Lancaster.[3] The capabilities and potentialities of the vidicon for high-quality film reproduction were first clearly recognized and demonstrated by R. G. Neuhauser of Lancaster. A detailed discussion of the theory and operation of this tube under film reproduction conditions is given by Neuhauser in the preceding paper in this *Journal*.[4]

We can most effectively evaluate vidicon performance by referring to the previously mentioned factors and reporting observations and measurements on these characteristics.

A. Resolution: The 1-in. vidicon with a 0.62-in. picture diagonal ($\frac{3}{8} \times \frac{1}{2}$ in. picture) has a limiting television resolution of 800 lines in the center of the raster, with a measured response of 35% at 350 lines compared with zero line number as a base.

B. The signal-to-noise ratio, measured as peak-to-peak signal to rms noise can be as high as 300 to 1. It is determined mainly by the shot noise-

characteristics of the input stage of the camera amplifier. High-performance, low-noise cascode amplifiers are used for this application.

C. The possibility of aperture response correction is particularly inviting with the vidicon because of the excellent signal-to-noise relation. For example, it is possible to raise the aperture response from 35% to 100% at 350 lines resolution by suitable techniques and still maintain a signal-to-noise ratio of 100 to 1. This improves horizontal resolution, but does not affect vertical resolution. Overall tests indicate that the process is definitely necessary for all pickup tubes, but can be used only where signal-to-noise performance is not sacrificed.

D. The gray-scale or transfer characteristic, which is inherent in the vidicon surface itself, has a log-log slope of 0.65 when signal output current is plotted against light on the photoconductive target. (This gamma is complementary to the kinescope transfer gamma characteristic, requiring no further correction in the video amplifiers.) A dynamic range of 150 to 1 or more in the usual gray-scale logarithmic test wedge can readily be demonstrated. With the iconoscope, 50 to 1 represents a value which can be attained only with special precautions. The slope is constant over a wide range of lighting and does not have the "rubbery" or variable gamma handicap of the iconoscope

E. Film-reproduction range and latitude are wide, due both to the low gamma and to the constant character of the signal output – light input characteristic. Normal shifts in print density produce very little change in quality since these can be compensated by either a change of video gain or projector light output. The high signal-to-noise ratio initially available makes this possible.

F. Light source requirements under typical conditions, and using commercially available lenses, are of the order of 300 ft-c, average, measured at the film gate. Since practically all intermittent-type television motion-picture film projectors used with the iconoscope have an exposure shutter opening of approximately 7%, phased under blanking, this 300-ft-c average corresponds to about 4000-ft-c peak. Optimum vidicon results are obtained using approximately $\frac{1}{3}$ of the maximum light output available in standard television projectors designed for use with the iconoscope. Sensitivity is deliberately sacrificed for improved performance by the use of a low signal-electrode voltage. The decrease in light requirements nevertheless prolongs projector lamp life greatly.

G. Since the vidicon tube is essentially an orthicon or low-velocity device as far as the scanning process is concerned, there is inherently no spurious shading signal developed. This contrasts very favorably with the iconoscope where elaborate precautions in edge lighting and waveform cancellation are necessary to minimize a normally large spurious signal. In the vidicon, no electrical shading cancellation signals are required, thus resulting in equipment and operational simplifications. In early models of vidicons, there were problems of maintaining uniform sensitivity of the photoresistive signal-electrode, so there was unequal signal output at the edges as compared to the center of the raster. Improvements in production techniques have made such variations negligible.

By operating the vidicon signal-electrode at low voltages for motion-picture film use, the decreased dark current of the device and the improvement in lag and burn characteristics greatly outweigh the loss of light sensitivity. High light sensitivity is vital for direct pickup cameras, but is of only casual interest in motion-picture reproduction.

H. Black-level reference in the vidicon is clean-cut and definite since the output resistor signal voltage, even on a d-c basis, is a function only of light on the raster. Thus, the zero signal or black reference is obtained directly, merely by blanking the scanning beam during the horizontal return interval. Standard clamping techniques can thus be used for automatic d-c set or black-level control.

I. Nonsynchronous operation of the projector with respect to the synchronous generator is a desirable attribute of a film-reproduction chain. In smooth network operation, it is often necessary to insert commercials or local film material in station-break intervals. Present techniques call for: fading to black; dropping network synchronizing signal; switching to local synchronous generator, which is locked to and properly phased with the local a-c power supply; and operating the iconoscope film chain conventionally. All of this is essential because of the necessity for exposing the iconoscope during the vertical blanking interval. Misphasing or nonsynchronous operation produces the well-known iconoscope application bar whose amplitude may be 10 to 20 times the useful normal video signal. Several synchronous projector drives, providing driving power with frequency controlled by the synchronous generator, have met with some success in solving this problem. By comparison, the vidicon behaves beautifully under nonsynchronous projector conditions. With a projector light exposure pulse of 7% of vertical field time, standard iconoscope exposure conditions, the "application pulse" signal is perceptible to a critical viewer, but is not particularly annoying. With longer application times, 30 to 65%, available with present 3–2 television projectors, such as the RCA TP-6A, the transition from "Light On" to "Light Off" is not detectable even to the most critical viewer. Long-application time also cuts down the peak illumination requirements. This means either smaller projector lamps or increase in projector lamp life by a factor of 10, or even more. Inserts in network program can thus be made merely by operating the projector from the local power supply with the local synchronous generator tied to network through a Genlock or similar device. The importance of such a feature will increase as network-to-local operation techniques are refined.

J. The "unattended operation" possibilities of the vidicon camera appear unusually attractive. Tests with a wide range of film material have shown that it is practically unnecessary to ride video gain. Black-level control is completely automatic, and there are no shading knobs provided or required. The controls are inherently stable and simple. In principle, the only two variables which require adjustment are wall voltage, which determines electrical scanning-beam focus and, therefore, picture resolution; and beam bias, controlling the number of electrons available for discharging the target. Even this last adjustment is noncritical in that the top beam-current requirement can easily be set by simple operational procedures, and any excess produces only secondary deteriorations in resolution due to increased scanning-spot size at lower grid biases. The vidicon is far less critical to set up and operate than the image-orthicon tube. That this is so follows from the fact that in the vidicon the useful video signal is generated only by the electrons flowing through the photoresistive signal electrode, while in the image orthicon, the video signal is obtained from the "return" electrons of the scanning beam, making it essential to adjust beam current very carefully to maintain "percentage modulation" at a high value.

Extensive tests show that the inherent stability of the vidicon tube and camera circuits is sufficiently high to make "unattended operation," using only a

bare minimum of monitoring and adjustments, a practical reality. This is believed to be of great importance to the television broadcaster.

This paper up to the present moment encroaches on the territory which is normally the province of the pickup-tube development engineer. However, tube and camera performance are so intimately related that it is practically impossible to draw a sharp dividing line between the two activities and still present an informative picture of developments and progress.

Features of Vidicon Camera Design

The vidicon camera system, which will now be described, is the third model resulting from information acquired in the advance development phases of the study.

The general philosophy of approach was based on the following goals:

1. The camera itself should be as small as possible so that it can be mounted directly on either a 16mm or 35mm projector or integrated into an optical multiplexing system.
2. The control circuits should be rack mounted for ease of maintenance and performance check. This has obvious advantages over locating them in a chassis set in a desk-type operating console, with poor accessibility.
3. The control panel containing the various operating and setup controls should be capable of location remote from the rack, should contain no electron tubes, and its connecting cables should not carry any signals except variable d-c voltages.

Following this approach, the camera contains only the vidicon tube, focus and deflection coils, a high-performance cascode amplifier, a low-impedance video output stage and a vidicon blanking amplifier.

Since the deflection requirements are relatively modest, horizontal deflection is supplied to the camera from a rack-mounted deflection amplifier through a coaxial conductor in the standard camera cable. A constant resistance termination is used, with the horizontal deflection coils as one of the termination elements. Suitable circuits are used for protection of the vidicon tube in the event of scanning failure. Regulated focus field current and other required operating waveforms are supplied to the camera from the rack chassis by conventional methods.

Other elements of the rack chassis assembly perform such functions as high-peaking to compensate for the effect of vidicon input shunt capacity, aperture compensation,[5] final blanking, clamping, clipping and addition of synchronizing signals. A standard RMA signal of 1.0 v is produced across the usual 75-ohm coaxial distribution line.

Figure 1 is a block diagram of the essential portions of the system. A vidicon camera mounted directly on a TP-6A 16mm Projector is shown in Fig. 2, and Fig. 3 is a detailed view of the vidicon camera.

Figure 4 shows the general appearance of the junction chassis; the focus, deflection, and protection assembly; the final processing amplifier; and the control panel. In an actual operational installation, all of the units except the control panel are mounted in a standard broadcast-type rack and are interconnected by suitable plugs and cables. The control panel is usually installed horizontally below a master monitor for convenience in operation.

Television Film Projectors

It can be mentioned that the vidicon, because of its well-behaved storage characteristics, can be used with any projector, continuous or intermittent, with long- or short-application time, which has suitable television conversion features. These are implied in the requirement of translating 24 film frames/sec into 30 complete television

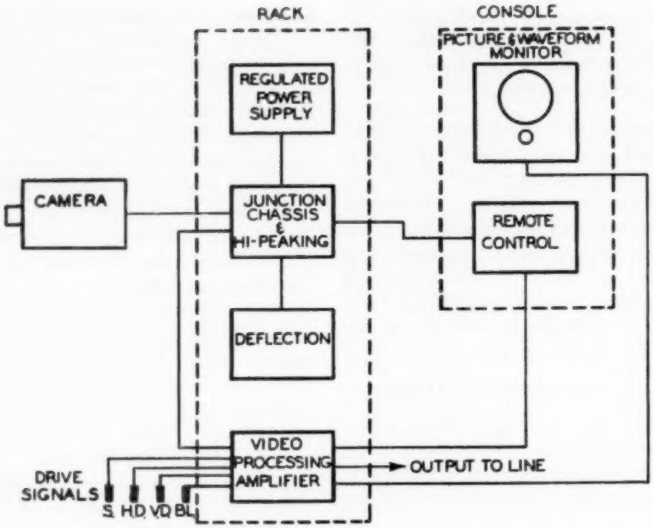


Fig. 1. Block diagram — vidicon film camera system.

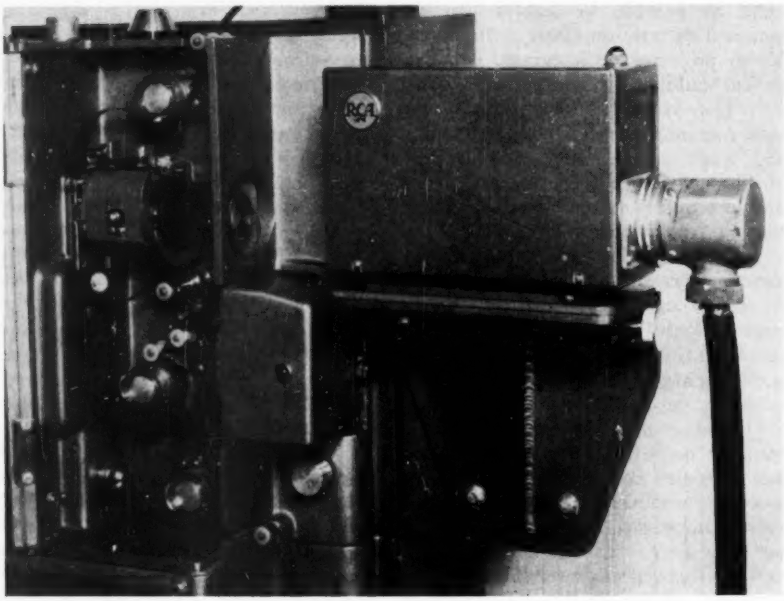


Fig. 2. Vidicon camera mounted on TP-6A 16mm Film Projector.

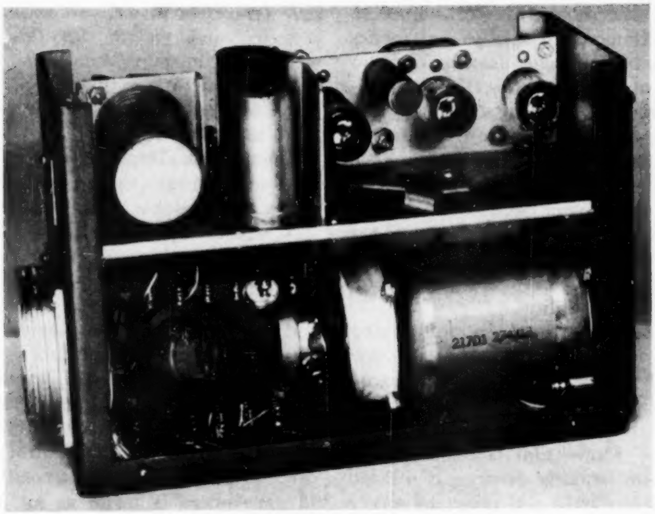


Fig. 3. Details of the vidicon camera.

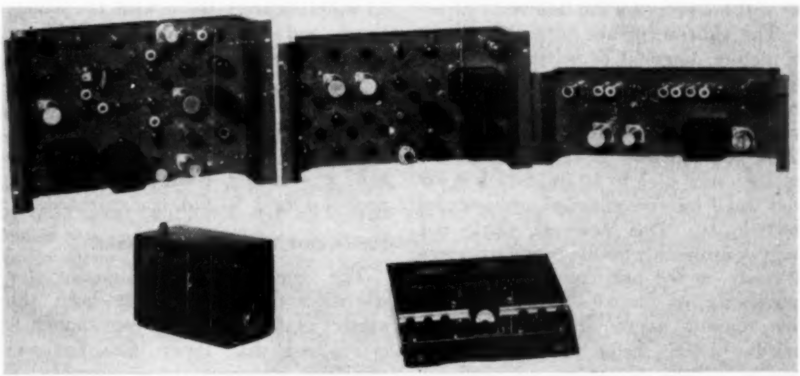


Fig. 4. Camera, rack chassis and control panel.

rasters in the same interval. Thus, there is a wide field of choice and the possibility of continuing to use, with complete satisfaction, the large number of projectors which are already in commercial broadcast operation.

The Multiplexing Problem

One of the major problems of the television broadcaster is to provide smoothness or continuity in programming without paying a high price in complexity of duplicated equipment, operating procedures and space requirements. This is particularly true with the smaller broadcasting stations which often show a film feature, insert 15-sec film spot commercials, slide or opaque commercials, then station identifications, and go back to film. They

have become thoroughly accustomed to going through such split-second tactics using only a single iconoscope film camera and multiplexing the information from two projectors, a Telop for opaques, and one or more transparency projectors, onto the iconoscope mosaic in the required sequence by means of mirror and douser techniques. They naturally expect that any improved device such as the vidicon camera will give them the same, or even more, operational flexibility.

With the iconoscope, the multiplexing problem is quite easily solved, since the diagonal of the photosensitive mosaic is 5 in. and the projector lens throw for the required magnification from 16mm or 35mm film is about 50 in. This 50-in. working distance is utilized for suitable mirror and projector source locations so that any one of three or more projection devices can be selected at will for program continuity.

The vidicon, on the other hand, has a picture diagonal of slightly less than $\frac{5}{8}$ of an inch, giving practically a unity magnification ratio for 16mm film and a 2:1 demagnification for 35mm frames. This consequently gives a lens throw of the order of 7 to 10 in., which is far too small for conventional multiplexing techniques. This, however, works out very conveniently for mounting a camera directly on the projector and gives the possibility of electrically multiplexing the outputs as required by program needs. There seems to be a definite trend in this direction by network originating stations.

This technique does not solve the problem for the small broadcaster who cannot afford the increased equipment, personnel and floor space required. A method of multiplexing has been devised and tested which appears to provide an excellent answer. The basis for operation is the creation of a working distance for accommodation of the required multiple mirrors and projector sources. This is done by projecting a real image in space, whose diagonal is 5 in., and picking up this image with a lens on the vidicon camera itself. A suitable field lens in the 5-in. image plane is used to direct the peripheral rays into the vidicon lens aperture. This technique allows the use of standard high-quality 16mm motion-picture lenses which are available at reasonable cost.

A similar application of relay lens techniques has been used in the RCA color camera and has given very good results from the viewpoint of resolution and detail contrast.[6] A schematic diagram of the elements of this system is shown in Fig. 5. With a carefully designed optical multiplexing system, the degradations introduced in the television picture by the additional lens process are definitely of second order. If the camera is made as an integral part of the optical system, the effects of projector vibration on image quality are no different from those with the iconoscope and direct projection. These are quite small in commercial operation.

Such an optical multiplexer is now in the product-design phase and is arranged to handle two film projectors, 16mm or 35mm, an opaque projector, and a remotely controlled preloaded projector for 2 × 2 in. transparencies.

16mm and 35mm Film Material

The question of film quality for television reproduction has been the subject of much study. Even though it is realized that 16mm film has tremendous commercial advantages in first cost, projector cost, storage requirements, air express shipping charges, fire code restrictions, and many other factors, the fact still remains that the best 16mm prints are none too good for television. An equivalent limiting television resolution of over 400 lines with 16mm release prints is rare. This contributes nothing to overall quality. By comparison, 35mm prints on the average have much higher performance from the standpoint of resolution, gray

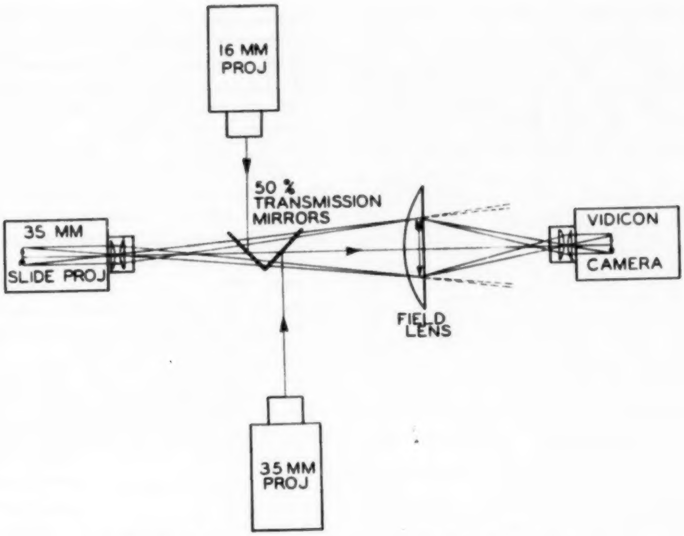


Fig. 5. Schematic diagram — optical multiplexer.

scale and grain. A great deal of the difference may well lie in the more careful control of exposure, step-printing and processing of 35mm film. It may be economically unsound to expend the same effort on production of 16mm film subjects. While there seems to be practically no likelihood of using 35mm film, except for network originations where the demands for high quality are extremely exacting, it is important to stress the fact that any technical improvements in 16mm film quality will be directly reflected in improved television picture quality.

A question often asked by broadcasters who have witnessed film reproduction with the vidicon camera is: "What are the results using the vidicon with poor-quality film?" The answer, unfortunately, is: "Poor." No television system, including the vidicon camera, can do very much to make film of poor technical quality look better on television than it looks on direct critical viewing. Perhaps a conservative way of expressing the same idea is to say that the system should introduce a minimum amount of deterioration in the translation of the optical information into a television picture signal.

Conclusions

Our study of the possibilities inherent in the use of the vidicon camera for high-quality reproduction of motion-picture film has been going on for about two years. During the last six months, the results have been observed by a wide range of critical television broadcasting observers, both in the laboratory and at the NARTB Convention at Los Angeles. The comments on reproduction fidelity, gray-scale reproduction, signal-to-noise ratio and operational stability have been extremely gratifying. We believe that the vidicon approach to motion-picture reproduction represents the most promising method of high-quality reproduction now available, and hope that its use in commercial broadcasting will continue to justify the enthusiasm which has been aroused during its development.

Acknowledgments

We acknowledge with pleasure the cooperation of R. G. Neuhauser, F. S. Veith and Dr. R. B. Janes, of RCA Lancaster, in the solution of many tube and circuit problems, and the help of Dr. O. H. Schade in providing a firm basis for evaluation of performance. The advance-development phase of the problem owes much to E. M. Gore and S. L. Bendell of RCA Victor, Camden. The commercial embodiment of the equipment is due to the efforts of N. L. Hobson and F. E. Cone of the Broadcast Equipment Section.

References

1. H. N. Kozanowski, "Improved television picture performance," *Broadcast News, 67:* Jan.-Feb. 1952.
2. P. K. Weimer, S. V. Forgue and R. R. Goodrich, "The vidicon photoconductive camera tube," *RCA Rev., XII:* 306–313, Sept. 1951.
3. B. H. Vine, R. B. Janes and F. S. Veith, "Performance of the vidicon, a small developmental television camera tube," *RCA Rev., XIII:* 3–10, Mar. 1952.
4. R. G. Neuhauser, "Vidicon for film pickup," *Jour. SMPTE, 62:* 142–152, Feb. 1954.
5. R. C. Dennison, "Aperture compensation for television cameras," *RCA Rev., XIV:* 569–585, Dec. 1953.
6. L. T. Sachtleben, D. J. Parker, G. L. Alee and E. Kornstein, "Image orthicon color television camera optical system," *RCA Rev., XIII:* 27–33, Mar. 1952.

Screen Brightness Committee Report

By W. W. LOZIER, Committee Chairman

THIS REPORT will review progress since the last formal report of the Committee presented to the Society at its October 1952 meeting.[1] It will also summarize the present status of various projects on the occasion of the completion of the writer's term of office as Chairman.

1. Subcommittee on Instruments and Procedures: This group under the chairmanship of F. J. Kolb, Jr., has prepared its report "Specifying and Measuring the Brightness of Motion Picture Screens," which was published in the October 1953 *Journal.*[2] This report gives an exceptionally thorough analysis of the requirements, specifications and methods of use for various types of meters ranging from the research-type meter, which will do a most complete job of measuring all phases of intensity of incident illumination and reflected brightness over all portions of the motion-picture theater, on down to the most limited type of meter which will determine only the total luminous output of the projector without giving any information as to how this light is distributed over the picture screen and to the motion-picture audience. Having completed its assignment, this Subcommittee has now been disbanded.

It is gratifying to the Committee to note that screen-brightness meters embodying many useful and desirable features have recently become commercially available.[3]

Submitted on December 29, 1953, by W. W. Lozier, National Carbon Company, Division of Union Carbide and Carbon Corp., Fostoria, Ohio.

2. Subcommittee on Projection Screens: New industry developments have been announced with such frequency over the past several months as to prevent this group from bringing its work to a conclusion. This group, originally set up to prepare standards of whiteness and brightness of motion-picture screens, will need to consider, in addition to the familiar matte-type screen, the other types of screens which have recently come into prominence.

3. Subcommittee on Illumination Practices: This group has likewise been unable to carry out its assignment due to pressure of other activities. Their task of preparation of recommended practices concerning distribution of illumination on motion-picture screens should be an important future committee activity.

4. *Subcommittee on Screen Photometry:* This group, recently formed under the chairmanship of Gerhard Lessman has been given the assignment of definition of terms and description of methods necessary for determination of the important photometric characteristics of screens, with special reference to the polarization properties so important to stereoscopic motion pictures. This group has been at work only a short time, but is expected to produce important results.

Revision of Screen-Brightness Standard: A revision of American Standard Screen Brightness for 35mm Motion Pictures, originated by the Committee, has recently been approved and issued as PH22.39-1953.[4]

Screen Brightness for 16mm Laboratory Review Rooms: The Screen Brightness Committee is assisting the Laboratory Practice Committee in the formulation of a standard for the brightness of the screens used for viewing 16mm film prints in the laboratory review rooms.

Symposium on Screen Brightness: The Committee sponsored a symposium of five papers presented at the Spring 1953 Convention of the Society in Los Angeles and later published as Part II of the August 1953 issue of the *Journal*.[5] These five papers covered such subjects as screen-brightness meters, carbon-arc projection systems, relation of screen brightness to picture quality and the effects of stray light.

Conclusion: Although much important and useful information has become available during the past few years, there remains a rich field of activity for the Committee during future years. In addition to the discovery and dissemination of new information, there remains the important task of translating existing knowledge into useful recommendations and standards to improve the quality of motion pictures.

References

1. W. W. Lozier, "Screen Brightness Committee Report," *Jour. SMPTE, 59:* 524–525, Dec. 1952.
2. F. J. Kolb, Jr., "Specifying and measuring the brightness of motion-picture screens," *Jour. SMPTE, 61:* 533–556, Oct. 1953.
3. Frank F. Crandell and Karl Freund, "New photoelectric brightness spot meter," *Jour. SMPTE, 61:* 215–222, Aug. 1953.
4. American Standard, Screen Brightness for 35mm Motion Pictures, PH22.39-1953, *Jour. SMPTE, 60:* 630, May 1953.
5. Symposium on Screen Brightness (5 papers), *Jour. SMPTE, 61:* 213–272, Aug. 1953.

The Committee

W. W. Lozier, *Chairman*

H. J. Benham	L. J. Patton
F. E. Carlson	O. W. Richards
M. H. Chamberlin	Leonard Satz
B. S. Conviser	Ben Schlanger
Philip Cowett	Allen Stimson
E. R. Geib	C. R. Underhill
L. D. Grignon	G. H. Walter
A. J. Hatch, Jr.	H. E. White
L. B. Isaac	A. T. Williams
W. F. Kelley	D. L. Williams
F. J. Kolb, Jr.	J. J. Zaro
Gerhard Lessman	

Reaffirmations of Standards — 1953

Listed below are 11 American Standards, approved by the appropriate ASA committees October 1, 1953, as Reaffirmations. The only change from the previous edition of each is in the PH designation. Included are the dates of prior *Journal* publication of the complete standards.

PH22.27-1947, Method of Determining Transmission Density of Motion-Picture Films (includes Z38.2.5-1946), Mar. 1948, p. 283.

PH22.37-1944, Raw Stock Cores for 35mm Motion-Picture Film, Sept. 1946, p. 262.

PH22.46-1946, 16mm Positive Aperture Dimensions and Image Size for Positive Prints Made From 35mm Negatives, Apr. 1946, p. 298.

PH22.47-1946, Negative Aperture Dimensions and Image Size for 16mm Duplicate Negatives Made from 35mm Positive Prints, Apr. 1946, p. 299.

PH22.60-1948, Theatre Sound Test Film for 35mm Motion-Picture Sound Reproducing Systems, Nov. 1948, p. 539.

PH22.62-1948, Sound Focusing Test Film for 35mm Motion-Picture Sound Reproducers (Laboratory Type), Nov. 1948, p. 541.

PH22.65-1948, Scanning-Beam Uniformity Test Film for 35mm Motion-Picture Sound Reproducers (Service Type), Nov. 1948, p. 542.

PH22.66-1948, Scanning-Beam Uniformity Test Film for 35mm Motion-Picture Sound Reproducers (Laboratory Type), Nov. 1948, pp. 543–544.

PH22.67-1948, 1000-Cycle Balancing Test Film for 35mm Motion-Picture Sound Reproducers, Nov. 1948, p. 545.

PH22.69-1948, Sound Records and Scanning Area of Double Width Push-Pull Sound Prints, Normal Centerline Type, Nov. 1948, p. 547.

PH22-70-1948, Sound Records and Scanning Area of Double Width Push-Pull Sound Prints, Offset Centerline Type, Nov. 1948, p. 548.

Six Proposed American Standards PH22.42, –.45, –.57, –.88, –.98 and –.99

Three proposed revisions of American Standards and three proposed new American Standards are published on the following pages for a 3-month period of trial and criticism. Comments should be sent to Henry Kogel, Staff Engineer, prior to May 15, 1954. If no adverse comments are received, the six standards will then be submitted to the ASA Sectional Committee PH22 for further processing as American Standards.

All six standards are a product of and have been approved by the Sound Committee under the chairmanship of John Hilliard. The initial work on the three proposed standards on magnetic sound was done by the Magnetic Recording Subcommittee under the chairmanship of Glenn Dimmick.

Revision of Z22.42-1946, Z22.45-1946 and Z22.57-1947 was undertaken for the purpose of modifying the section on identification. However, in the process of review, several additional changes primarily of an editorial nature were made.

In PH22.42, the title was simplified, a section added on film stock, section 2.1.1 eliminated and it's specification made a part of section 1, Scope.

In PH22.45, the title was simplified, section 2.2.1, Resistance to Shrinkage, was deleted and section 2.4 was modified to be in accordance with present practice.

In PH22.57, the title was simplified, a negative tolerance was added to the specification of density, section 2.3.1, Resistance to Shrinkage, was deleted and the sound-track edge was indicated as the guided edge.

PH22.88, Magnetic Sound Specifications for 8mm Motion-Picture Film, was published previously in the July 1951 *Journal* for trial and comment. Exceptions were taken to the location and dimensions of the magnetic coating. These differences have now been resolved and the specifications made consistent with the 16mm magnetic sound proposal now before the Sound Committee.

PH22.98, and PH22.99 are relatively recent proposals and have not been published previously. — *HK.*

Proposed American Standard

16mm Sound-Focusing Test Film

(Second Draft)

PH22.42

Revision of Z22.42-1946

1. Scope

1.1 This standard specifies a test film to be used for checking the focus of the scanning beam of 16mm sound motion-picture projectors.

Type A — 7000-cycle recording for manufacturing and precision adjustment of sound focusing;

Type B — 5000-cycle recording for quick field adjustment of sound focusing.

2. Test Film

2.1 The test film shall have an originally recorded variable-density sound track heavily overmodulated and developed to high contrast so that the resultant track is essentially a square-wave track.

2.2 The sound track shall have correct azimuth to within ± 5 min of arc.

3. Film Stock

3.1 The film stock used shall be of the low-shrinkage, safety type, cut and perforated in accordance with American Standard PH22.12-1953, Dimensions for 16mm Film, Perforated One Edge, or the latest revision thereof approved by the American Standards Association, Incorporated.

4. Identification

4.1 Each film of Type A shall be marked **SMPTE — ASA — PH22.42 — 7000-Cycle Focusing.** Each film of Type B shall be marked **SMPTE — ASA — PH22.42 — 5000-Cycle Focusing.** This marking shall be printed lengthwise in the picture area, the spacing between consecutive titles to be approximately 12 in.

5. Film Length

5.1 The film shall be supplied in 100-ft lengths.

NOTE: A test film in accordance with this standard is available from the Society of Motion Picture and Television Engineers.

NOT APPROVED

Proposed American Standard **16mm 400-Cycle Signal-Level Test Film** (Third Draft)	**PH22.45** Revision of Z22.45-1946

1. Scope

1.1 This standard specifies a 400-cycle signal-level test film for use in testing 16mm sound motion-picture projection equipment.

2. Test Film

2.1 The test film shall have an originally recorded, direct-playback, positive variable-area sound recording at an amplitude of 0.0480 ± 0.0015 in. Each film shall be measured for amplitude and the measurements shall be made at a point approximately mid-length of the film and at points between 5 ft and 10 ft from each end.

2.2 The frequency of the recording shall be 400 ± 8 cycles per sec.

2.3 The density of the dark portion of the sound track shall be between 1.2 and 1.4. The density throughout the length of the film shall be as uniform as is consistent with the state of the art.

2.4 The combined base and fog density shall be 0.05 ± 0.01, measured as diffuse transmission density in accordance with American Standard Z38.2.5-1946, Diffuse Transmission Density, or the latest revision thereof approved by the American Standards Association, Incorporated.

2.5 The total harmonic distortion of the recording shall not exceed 5% and the fluctuation of the recorded level shall not exceed 2%.

2.6 Each film shall be run in a standard calibrated reproducer for the purpose of obtaining the level of recording; this level shall be compared with that of the standard control film and the difference shall be noted in the booklet furnished with each film.

3. Film Stock

3.1 The film stock used shall be of the low-shrinkage, safety type, cut and perforated in accordance with American Standard PH22.12-1953, Dimensions for 16mm Film, Perforated One Edge, or the latest revision thereof approved by the American Standards Association, Incorporated.

4. Identification

4.1 Each film shall be marked **SMPTE — ASA — PH22.45 — 400-Cycle Signal Level.** This marking shall be printed lengthwise in the picture area, the spacing between consecutive titles to be approximately 12 in.

5. Film Length

5.1 The film shall be supplied in 100-ft lengths.

NOTE: A test film in accordance with this standard is available from the Society of Motion Picture and Television Engineers.

NOT APPROVED

Proposed American Standard

16mm Buzz-Track Test Film

(Third Draft)

PH22.57

Revision of Z22.57-1947

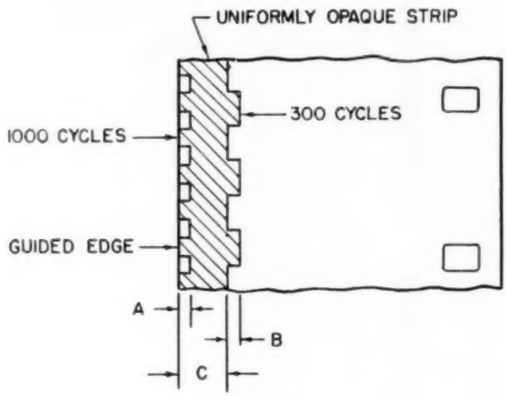
1. Scope

1.1 This standard specifies a buzz-track test film used for checking the position of the sound scanning beam in 16mm motion-picture sound reproducers.

2. Test Film

2.1 The test film shall have originally recorded 300-cycle and 1000-cycle signal tracks on either side of the central exposed strip as shown in the drawing.

2.2 The position of the tracks, weave in running film on the recorder included, shall be in accordance with the dimensions given in the table below:



Dimension	Inches	Millimeters
A	0.0200 $^{+0.0005}_{-0.0000}$	0.510 $^{+0.012}_{-0.000}$
B	0.018 $\pm$ 0.001	0.460 $\pm$ 0.025
C	0.0960 $^{+0.0000}_{-0.0005}$	2.440 $^{+0.000}_{-0.012}$

NOT APPROVED

2.3 The central exposed strip and the exposed portions of the two signal tracks shall have a density of $1.6^{+0.4}_{-0.0}$

3. Film Stock

3.1 The film stock used shall be of the low-shrinkage, safety type, cut and perforated in accordance with American Standard PH22.12-1953, Dimensions for 16mm Film, Perforated One Edge, or the latest revision thereof approved by the American Standards Association, Incorporated.

4. Identification

4.1 Each film shall be marked **SMPTE — ASA — PH22.57 — Buzz-Track.** This marking shall be printed lengthwise in the picture area, the spacing between consecutive titles to be approximately 12 in.

5. Film Length

5.1 The film shall be supplied in 100-ft lengths.

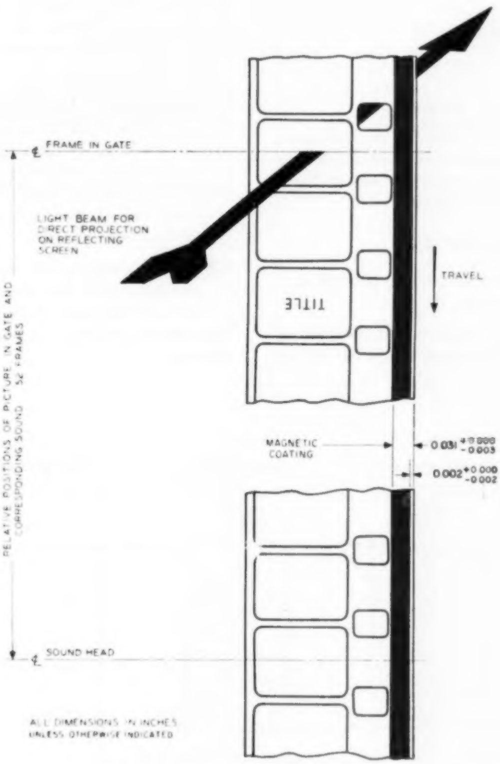
NOTE: A test film in accordance with this standard is available from the Society of Motion Picture and Television Engineers.

Proposed American Standard

Magnetic Sound Specifications for 8mm Motion-Picture Film

(Third Draft)

PH22.88



The magnetic coating in the above drawing is on the side of the film toward the lamp on a projector arranged for direct projection on a reflection-type screen.

Projection Speeds — 24 frames per sec for professional use.
18 frames per sec for amateur use.

NOT APPROVED

Proposed American Standard

35mm Magnetic Flutter Test Film

(Third Draft)

PH22.98

1. Scope

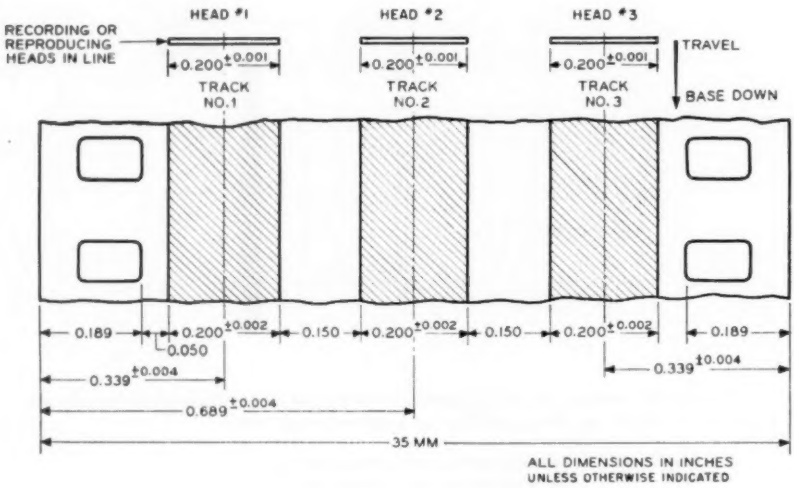
1.1 This standard specifies a 3000-cycle, fully coated, magnetic sound test film for use in determining the presence of flutter in 35mm magnetic sound reproducers.

2. Test Film

2.1 The test film shall have an original magnetic sound recording.

2.2 The coating position and direction of travel shall be as specified in American Standard PH22.86-1953, 200-Mil Magnetic Sound Tracks on 35mm and 17½mm Motion-Picture Film, or the latest revision thereof approved by the American Standards Association, Incorporated, and the base shall be coated from one row of perforations to the other row, or from edge to edge.

2.3 Three sound records shall be recorded in accordance with the dimensions specified in American Standard PH22.86-1953, or the latest revision thereof, and as shown in the drawing.



NOT APPROVED

2.4 The recorded frequency shall be 3000 ± 25 cycles per sec with a recording speed of 96 perforations per sec or 90 ft per min.

2.5 The modulation of the recording shall be such that the total harmonic distortion does not exceed 2½%.

2.6 The total rms flutter of the sound recorder shall not exceed 0.1% and the flutter amplitude shall not exceed 0.05% (as defined in Proposed American Standard Z57.1, Method of Determining Flutter Content of Sound Recorders and Reproducers).

3. Film Stock

3.1 The film stock used shall be of the low-shrinkage, safety type, cut and perforated in accordance with American Standard Z22.36-1947, Cutting and Perforating Dimensions for 35-Millimeter Motion Picture Positive Raw Stock, or the latest revision thereof approved by the American Standards Association, Incorporated.

4. Film Length

4.1 The film shall be supplied in 50-ft lengths or multiples thereof.

5. Identification

5.1 Each test film shall have suitable identification markings.

Proposed American Standard **35mm Magnetic Azimuth Alignment Test Film** (Third Draft)	**PH22.99**

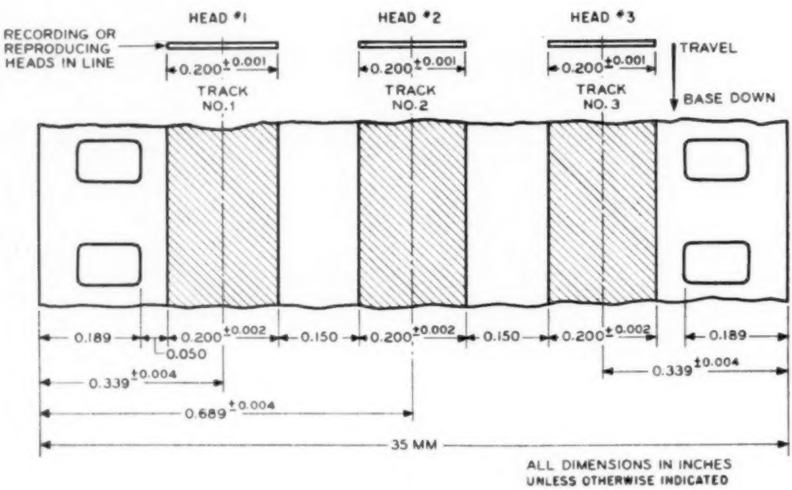
1. Scope

1.1 This standard specifies a test film to be used in aligning the azimuth of magnetic heads on 35mm magnetic recording and reproducing equipment where the head width is not greater than 0.200 in.

2. Test Film

2.1 The test film shall have an original recording of an 8000-cycle sinusoidal tone with a film speed of 96 perforations per sec or 90 ft per min.

2.2 Three sound records shall be recorded in accordance with the dimensions specified in American Standard PH22.86-1953, 200-Mil Magnetic Sound Tracks on 35mm and 17½mm Motion-Picture Film, or the latest revision thereof approved by the American Standards Association, Incorporated, and as shown in the drawing.



NOT APPROVED

2.3 The sound record shall have correct azimuth to within ± 3 min of arc.

2.4 The recorded level at 8000 cycles shall be that level which results from an input current to the magnetic head which is 1 db below the 400-cycle current input which would give a total harmonic distortion of 2½% when that 400-cycle tone is reproduced.

2.5 The coating position and direction of travel shall be as specified in American Standard PH22.86-1953, or the latest revision thereof, and the base shall be coated from one row of perforations to the other row, or from edge to edge.

3. Film Stock

3.1 The film stock used shall be of the low-shrinkage, safety type, cut and perforated in accordance with American Standard Z22.36-1947, Cutting and Perforating Dimensions for 35-Millimeter Motion Picture Positive Raw Stock, or the latest revision thereof approved by the American Standards Association, Incorporated.

4. Film Length

4.1 The film shall be supplied in 50-ft lengths or multiples thereof.

5. Identification

5.1 Each test film shall have suitable identification markings.

American Standards PH22.75–1953 and PH22.90–1953 16mm A and B Windings, and Aperture Calibration of Lenses

Two American Standards approved by the American Standards Association on December 17, 1953, are published on the following pages. These two standards were published previously for trial and comment in the October 1952 and February 1953 *Journals*, respectively.

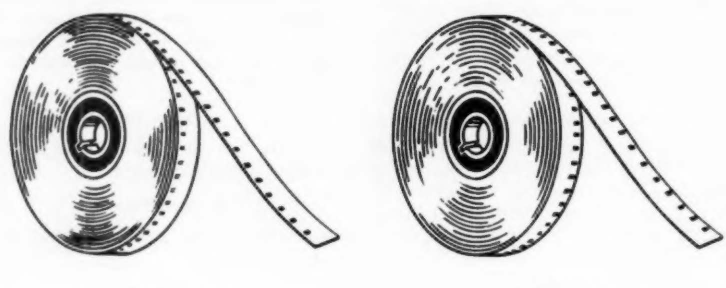
American Standard

A and B Windings of 16mm Film, Perforated One Edge

ASA
Reg. U.S. Pat. Off.

PH22.75-1953

*UDC 778.5



Winding A
Emulsion side in

Winding B
Emulsion side in

(With the types of winding described below, the emulsion side of the film shall face the center of the roll.)

1. Scope

1.1 The purpose of this standard is to insure a uniform method of designating the type of winding (the location of the perforated edge) when ordering or describing 16mm raw-stock film with the perforations along one edge.

2. Film on Cores for Darkroom Loading

2.1 When a roll of 16mm raw stock, perforated along one edge, is held so that the outside end of the film leaves the roll at the top and toward the right, winding A shall have the perforations along the edge of the film toward the observer, and winding B shall have the perforations along the edge away from the observer. No preference for either type of winding is implied, since both types are required for use on existing equipment.

3. Film on Spools for Daylight Loading

3.1 When the film is wound on a spool with a square hole in one flange and a round hole in the other flange, it shall be specified as winding B when wound as described for B above and with the square hole on the side away from the observer. Windings other than winding B, on spools, are considered as special-order products.

Appendix

(This Appendix is not a part of American Standard A and B Windings of 16mm Film, Perforated One Edge, PH22.75-1953.)

A1. The types of winding covered by this standard are limited to those which are in general use.

A2. It is recognized that film on spools, with a square hole in one flange and a round hole in the other, can be wound in other ways than that described as winding B, and that for special purposes these windings may be supplied commercially.

Approved December 17, 1953, by the American Standards Association, Incorporated
Sponsor: Society of Motion Picture and Television Engineers

*Universal Decimal Classification

Printed in U.S.A.
ASA1½M254

Price, 25 Cents

American Standard

Aperture Calibration of Motion-Picture Lenses

ASA
Reg. U.S. Pat. Off.

PH22.90-1953

*UDC 778.5

1. Scope

1.1 The purpose of this standard is to define the *f* and *T* numbers used to express the relative aperture of a photographic objective. A second purpose is to establish means for calibrating the diaphragms of objectives in both the *f* and *T* systems, with suitable tolerance specifications.

1.1.1 The *f* number of a lens represents a true geometrical measure of the relative aperture.

1.1.2 The *T* number is a photometrically determined measure of the relative aperture of a lens adjusted to take proper account of the lens transmittance, so that the illuminance in the center of the lens field will be the same for all lenses at the same *T*-stop setting. This assumes that the object is a uniform plane diffusing surface perpendicular to the lens axis.

1.2 It should perhaps be mentioned that the photometric calibration of a lens diaphragm as contemplated by the *T* system of diaphragm marking established by this specification is only one step in extending the control for the purpose of producing negatives of a desired uniform density. The density of a negative is dependent upon the illumination and reflectance of the object photographed, the correctness of the diaphragm marking, the absorption of the lens, the accuracy of timing of the exposure, the uniformity of the emulsion employed, and complete control of the processing. The application of the *T*-stop system is designed to improve the control as regards correctness of diaphragm marking and absorption of the lens. The importance and need for this particular control increases as the control of the other factors enumerated is improved.

2. Theory

2.1 The illuminance at the center of the image of a uniform plane extended object perpendicular to, and centered on, the lens axis, when the lens has a circular aperture, is given by:

$$E = \pi t B \sin^2\theta \qquad (1)$$

In this formula: E is the illuminance in lumens per unit of area; t is the lens transmittance, expressed as the ratio of emerging flux to entering flux for a beam sufficiently narrow to pass through the lens without obstruction by the lens mount; B is the object luminance in candles per square unit; and θ is the semi-angle of the cone subtended by the circular exit pupil of the lens at the point where the lens axis intersects the image plane.

2.2 If the lens can be assumed to be aplanatic, that is, to be free from spherical aberration and to satisfy the sine condition, and if the object is very distant, then the value of sin θ will be given by:

$$\sin\theta = \frac{Y}{f} \qquad (2)$$

where Y is the semidiameter of the circular *entrance* pupil of the lens and f is the focal length. The validity of this equation may be seen by reference to Fig. 1, remembering that, in a lens having the type of correction assumed in this paragraph, the principal planes of Gauss are in reality portions of spheres centered about the axial object and image points, respectively.

2.3 If the lens aperture is not circular, which will often occur when the iris is partly closed, the angle θ has no meaning. In such a case, we may define the *effective diameter, D'*, of the entrance pupil in terms of its area, A, by:

$$A = \frac{\pi D'^2}{4} \qquad (3)$$

Approved December 17, 1953, by the American Standards Association, Incorporated
Sponsor: Society of Motion Picture and Television Engineers

*Universal Decimal Classification

Printed in U.S.A.
ASA1½M254

Price, 50 Cents

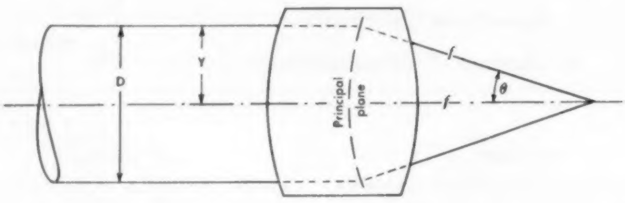


Fig. 1

whence $$D' = 2\sqrt{\frac{A}{\pi}} \qquad (4)$$

2.4 For an aplanatic lens, we may now replace $\sin\theta$ by $D'/2f$, and the image illuminance equation (1) becomes:

$$E = \pi\, t\, B\, (D'/2f)^2$$

whence by equation (4), we find:

$$E = t\, BA/f^2 \qquad (5)$$

3. Definition of *f* Number

3.1 For a lens of the type assumed, having a circular aperture, which is perfectly corrected for spherical aberration and satisfies the sine condition, and which is also assumed to form an image in air of a very distant object, the *f* number of the lens is defined by the equation:

$$f\text{ number} = \frac{f}{D} = \frac{1}{2\sin\theta_o} \qquad (6)$$

where θ_o is the semiangle of the cone subtended by the circular exit pupil of the lens at the point where the lens axis intersects the plane of the image of the assumed distant object, and the *entrance* pupil has a diameter, D.

3.2 If the entrance pupil is not circular, this relation becomes:

$$f\text{ number} = \frac{f}{D'} = \frac{f}{2}\sqrt{\frac{\pi}{A}} \qquad (7)$$

following the reasoning of Section 2.3.

3.3 If the aperture is circular, but the lens does not satisfy the sine condition, then f/D will not be equal to $1/(2\sin\theta)$. In such a case, the *f* number of the lens is to be defined by $1/(2\sin\theta)$ rather than by the ratio f/D. This value is chosen because both the image illuminance and the depth of field of the lens depend directly on $\sin\theta$. In such a lens, then, the marked *f* number will not be equal to the simple ratio of the focal length to the diameter of the entrance pupil.

3.4 The procedure for measuring the *f* number of a lens with a distant object is given in Section 11.

3.5 In terms of *f* number, equation (1), giving the image illuminance, becomes:

$$E = \pi\, t\, B/4(f\text{ number})^2 \qquad (8)$$

4. Effective and Equivalent *f* Number of a Lens Used at Finite Magnification

4.1 If a lens with a circular aperture is used to form an image at a finite magnification, m, the image illuminance will, as always, be given by equation (1).

4.2 The *Effective f number* of the lens, which is to be used to determine the image illuminance by equation (8), is then defined by:

$$\text{Effective } f\text{ number} = \frac{1}{2\sin\theta_m} \qquad (9)$$

where θ_m changes as the magnification m increases.

4.3 For an infinitely thin lens, or for a thick lens in which the entrance and exit pupils coincide with the first and second principal planes, respectively, and in which the light beam is limited only by the iris diaphragm, the Effec-

tive f number will be related to the f number by:

$$(\text{Effective } f \text{ number for magnification } m) = (f \text{ number})(1 + m) \quad (10)$$

4.4 However, many lenses cannot be regarded as being "thin," and in such cases the Effective f number at a finite magnification will not* be equal to the infinity f number multiplied by $(1 + m)$. However, the photographer knows from long experience that he should always multiply the marked f number of a lens by $(1 + m)$ in order to determine the Effective f number at a finite magnification, m. Therefore, in order that this procedure can continue to be used, it is suggested that if a lens is designed to work at or near some particular finite magnification, m, the aperture markings should be engraved with the "Equivalent f number" defined by:

$$\text{Equivalent } f \text{ number} = \left[\frac{\text{Effective } f \text{ number at magnification } m}{1 + m}\right] \quad (11)$$

5. Definition of T Number

5.1 When lenses are marked in accordance with the f system, differences of value in the factor t of equation (1) are completely ignored, with the consequence that for a given f-setting of the diaphragms, even though correctly marked, the exposures made with different lenses may vary greatly, this variation arising from a variation in the number of component elements of the different lenses and from the large differences in the values of transmittance that exist between coated and uncoated lenses. The T system defined in this section is a new system of diaphragm graduation designed to compensate for this variation. With the T system of graduation, the image illuminance in the center of the field is independent of the variations in lens structure enumerated above.

* For example, an afocal lens of symmetrical construction can be used as a printer or copying lens at unit magnification. The Effective f number is then equal to the f number of the half system, but since the focal length of the whole lens is infinite, no meaning can be given to the f number of the whole system. For other examples see: R. Kingslake, "The effective aperture of a photographic objective," J. Opt. Soc. Am., vol. 35, pp. 518–520 (1945).

5.2 For a lens used with a distant object, the T number is defined as the f number of an ideal lens having 100 percent transmittance and a circular aperture, which would give the same central-image illuminance as the actual lens at the specified stop opening.

5.3 Hence, for a lens with a circular aperture, following the argument of equation (8):

$$T \text{ number} = \frac{f \text{ number}}{\sqrt{t}} \quad (12)$$

and for a lens with an entrance pupil of any shape and area, A, the corresponding formula is:

$$T \text{ number} = \frac{F}{2}\sqrt{\frac{\pi}{tA}} \quad (13)$$

5.4 In practice, however, it is expected that the normal procedure will be to re-engrave the diaphragm ring on the lens at a series of definite T numbers, rather than to measure the T number corresponding to each of the existing marked f numbers.

5.5 It may be remarked again that the T number is a photometrically determined quantity, whereas the f number is a geometrical quantity. Since the T numbers are determined photometrically, they automatically take account of the size and shape of the aperture, the actual focal length of the lens, the lens transmittance, and any internally reflected stray light which may happen to strike the film at the center of the field (such as in a flare spot). It is implicit in the T number system of aperture markings that every lens should be individually calibrated.

5.6 For a lens designed to be used at finite magnification, the engraved T number will correspond to the Equivalent f number defined by equation (11).

5.7 The procedure for measuring the T number of a lens is given in Section 13.

6. Standard Series of Aperture Markings

6.1 The diaphragm ring of a lens shall be marked at every whole stop on either system. A "whole stop" is taken to represent an interval of double or half the image illuminance,

corresponding to a ratio of $\sqrt{2}$ or $\sqrt{0.5}$ in the diameter of a circular lens aperture. By convention, the series of whole stop numbers to be used are accurately:

0.71, 1.00, 1.41, 2.00, 2.83, 4.00, 5.66, 8.00, 11.3, 16.0, 22.6, 32.0, ...

6.2 These marks shall be engraved on the lens as follows: 0.7, 1, 1.4, 2, 2.8, 4, 5.6, 8, 11, 16, 22, 32. The maximum aperture of the lens shall be marked with its measured *f* number or *T* number, stated to one decimal place. These recommendations are in accordance with American Standard Lens Aperture Markings, Z38.4.7-1950.

6.3 In setting the lens aperture, it is assumed that the diaphragm ring will always be turned in the closing direction, and not in the opening direction; this is to eliminate backlash effects.

7. Subdivision of a Whole Stop

7.1 If it is desired to subdivide a "whole stop" interval, we may refer to a fraction, S, of a stop, defined so as to yield a ratio of image illuminance, *R*, equal to 2^S or $(0.5)^S$. Then, for any given illuminance-ratio, *R*, the corresponding fraction of a stop will be given by $S = (\log R)/(\log 2) = 3.32 \log R$. A few typical examples are given in the following table:

Fraction of a Stop (S)	Illuminance Ratio (*R*)
one-tenth	1.072 or 0.932
one-sixth	1.122 or 0.891
one-quarter	1.189 or 0.841
one-third	1.260 or 0.793
one-half	1.414 or 0.707
two-thirds	1.587 or 0.630
three-quarters	1.682 or 0.594
a whole stop	2.0 or 0.5

7.2 When engraving a lens, each whole stop interval may be divided into three subdivisions by dots or marks (not numbered), the dots being at "thirds of a stop," namely, 0.7, 0.8, 0.9, *1.0*, 1.13, 1.27, *1.4*, 1.6, 1.8, 2.0, 2.2, 2.5, *2.8*, 3.2, 3.6, *4.0*, 4.5 5.0, *5.6*, 6.3, 7.1, 8.0, 9.0, 10.0, *11.3*, 12.7, 14.2, *16*, 18, 20, *23*, 25, 28, 32, ...

7.3 Each stop interval is divided into three parts so that the lens apertures will agree with the exposure-meter markings stated in American War Standard for General-Purpose Photographic Exposure Meter, Z38.2.6-1946, 3.4.2, Relative Aperture Scale, page 6. The same cube-root-of-two series is used for the Exposure Index of a film. (See American Standard Method for Determining Photographic Speed and Exposure Index, Z38.2.1-1947, page 11.) One-third of a stop represents a logarithmic illumination ratio equal to 0.1, which is the transmittance of a neutral density of 0.1. The ratio of successive circular stop diameters is equal to $\sqrt[6]{2} = 1.123$.

8. Symbols

8.1 Lenses calibrated on the *f* system should bear the designation *f/* or *f:* followed by the numerals (see American Standard Lens Aperture Markings, Z38.4.7-1950).

8.2 Lenses calibrated on the *T*-stop system should bear the designation *T* or *T-* followed by the numerals.

9. Accuracy of Marking (*f* System)

9.1 The *maximum* opening of a lens on the *f* system shall be marked with an accuracy of ± 12 percent of area, or ± 6 percent of diameter.*

NOTE: Since in most factories a blanket calibration is generally used for the *f* apertures of a complete run of lenses of the same type, the smaller openings may be in error by ± 25 percent of area, or ± 12 percent of diameter (one-third of a stop), particularly in

* In accordance with American Standard Marking of Focal Length of Lenses, Z38.4.4-1942, the engraved focal length of *lenses for still picture photography*, must be within ± 4 percent of its true value, and in accordance with American Standard Lens Aperture Markings, Z38.4.7-1950, the measured diameter of the maximum entering beam shall be at least 95 percent of the quotient obtained by dividing the engraved focal length by the engraved *f* number. Thus by combining these tolerances we find that the diameter of the maximum lens aperture may be in error by as much as 9 percent. This represents an error in area of 18 percent, or one-quarter of a stop, which is felt to be unnecessarily large for the maximum aperture. The tolerances on aperture marking for motion-picture objective lenses allows less latitude than that provided for still picture camera lenses, because of the stricter requirements in cinematography on the same continuous length of film using different lenses.

short-focus lenses. These figures are based on the assumption that the iris will always be closed down to the desired aperture and not opened up from a smaller aperture, to eliminate backlash effects.

10. Accuracy of Marking (T System)

10.1 Since each lens is individually calibrated, an accuracy of one-sixth of a stop (10 percent in illumination or 5 percent in diameter) becomes entirely possible throughout the whole range of the diaphragm scale. This is assuming that the diaphragm is always closed down to the desired aperture and not opened up from a smaller aperture, to eliminate backlash effects.

10.2 Alternatively, the manufacturer should be prepared to guarantee this accuracy even though each stop marking may not be individually determined.

10.3 It may be of interest to indicate the approximate magnitude of this tolerance. Since 5 percent in diameter corresponds to 5 percent in f number, a lens of aperture nominally $f/2$ may be anywhere between $f/1.90$ and $f/2.10$. A lens nominally $f/4.5$ may lie between $f/4.28$ and $f/4.72$; and a nominal $f/8$ may lie anywhere between $f/7.6$ and $f/8.4$.

11. Measurement of f Apertures (Distant Object)

11.1 The procedure for measuring the f number of any lens having a circular diaphragm aperture is described in American Standard Methods of Designating and Measuring Apertures and Related Quantities Pertaining to Photographic Lenses, Z38.4.20-1948, paragraph 3.

11.2 If the entrance pupil is noncircular, it is necessary to measure its area. This may be done conveniently by mounting a point source of light, such as a small hole in front of a lamp bulb or a 2-watt zirconium lamp, at the rear focal point of the lens, and allowing the light beam which emerges from the front of the lens to fall upon a piece of photographic material. After processing, the recorded area is measured with a planimeter and applied in equation (7). If the lens is too small for this procedure to be employed, it may be placed in a suitable telecentric projector working at a known magnification (a workshop profile projector is suitable), the back of the test lens being towqrds the source of light. The entrance pupil then will be projected onto the screen of the projector at a known magnification, whence its area can be determined with a planimeter.

12. Measurement of f Apertures (Near Object)

12.1 To measure the Effective f number of a lens when used with a near object, it is necessary to determine the angle θ in equation (9). This may be done by using a point source of light at the correct axial object position, and measuring the diameter of the emerging beam at two widely separated planes a known distance apart. A simple computation will enable the semicone-angle θ to be determined.

12.2 The *Effective* f number is defined by $1/(2 \sin \theta)$; and the *Equivalent* f number for engraving on the lens barrel will then be equal to the Effective f number divided by $(1 + m)$, where m is the image magnification. (See section 4.4 above.)

13. Photometric Calibration of a Lens

13.1 General Requirements

13.1.1 Since *T*-stops are based on a measurement of the illumination produced by the lens at the center of the field, it is first necessary to define the latter term. For the purpose of illumination or flux measurements, the term "center of the field" shall be taken to mean any area within a central circle approximately 3 mm in diameter for 35mm or 16mm frames, or 1.5 mm in diameter for 8mm frames.

13.1.2 The light used in making the determination shall be white,* and the sensitivity characteristic of the photoelectric receiver

* Specifically, a tungsten filament lamp operating between 2900 and 3200 K.

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shall approximate that of ordinary panchromatic emulsion.† It is considered that these factors are not at all critical and no closer specification than this is necessary. Obviously, errors will arise if the lens has a strongly selective transmission, but such lenses would be undesirable for other reasons.

13.1.3 The incident light shall fill a circular field whose angular diameter is no more than 10 degrees in excess of the diagonal of the intended angular field of the lens itself. During measurement, the light shall traverse the lens in the direction ordinarily employed in photography.

13.1.4 The lens should be carefully examined before calibration to ensure that there are no shiny regions in the barrel which would lead to flare or unwanted stray light, since this would vitiate the measurements badly. The lens surfaces should be clean.

13.2 Corner-to-Center Ratio. Having calibrated the stop markings of the lens on the *T* system by one of the methods to be described, the observer may, if desired, determine in addition the ratio of corner illumination to center illumination, at full aperture and preferably at other apertures also. For this purpose the 3-mm (or 1½-mm) hole shall be used first at the center of the field, and then moved outwards until its rim is touching the top and side limits of the camera gate. This distance is shown in Table 1.

Table 1

Gate, Mm	Radial Shift of Hole, Mm
35 (16.03 × 22.05)	11.5
16 (7.47 × 10.41)	4.5
8 (3.51 × 4.80)	2.0

13.3 Extended-Source Method of *T*-Stop Calibration (distant object)

13.3.1 This method of lens calibration has been described by Gardner[13] and Sachtleben,[9] the underlying theory being given by McRae.[4] It is based on filling the lens with light from an extended uniform source, and placing a metal plate *in the focal plane* of the lens with a 3-mm hole (or 1.5-mm for 8mm film) at its center. The light flux passing through the hole is measured by a photocell arrangement. This flux is then compared with the flux from the same source passing through the same hole from an open circular aperture of such a size and at such a distance from the plate that it subtends the desired angle θ referred to in equation (2) above. The greatest care is necessary to ensure that the extended source is really uniform, and also constant throughout the measurements. The open circular aperture is used as the "ideal lens with 100 percent transmittance" referred to in Section 5.2.

13.3.2 It should be noted that this procedure measures the *T*-stop Aperture Ratio of the lens directly, regardless of whether or not the lens is aplanatic.

13.3.3 In practice, the photocell reading for each whole *T*-stop number is first determined for a series of open apertures, at a fixed distance from the plate. The lens is then substituted for the open aperture with the 3-mm hole accurately in its focal plane, and the iris of the lens is closed down until the photocell meter reading produced by the lens is equal to each of the successive open-hole readings. The full *T*-stop positions are then marked on the diaphragm ring of the lens. The intermediate third-of-a-stop positions may be found with sufficient accuracy by inserting a neutral density filter of 0.1 or 0.2 behind each open aperture in turn and noting the corresponding photocell readings.

13.3.4 Table 2 which lists aperture diameters may be useful. They are based on a distance of 50 mm from aperture to plate. (It is important to remember the difference between sine and tangent, and that the aperture diameter is *not* found merely by dividing 50 mm by the *T* number.)

13.3.5 A single set of apertures is sufficient to calibrate lenses of all focal lengths, since the only factor involved is sin θ, and that is fixed by the aperture used. The apertures should be bevelled to a sharp edge, and well blackened on both sides.

13.3.6 The extended source should be uniformly bright over its useful area to within ± 3 percent. (This can be tested with a suitable

† A suitable cell is one having an S-3 surface, combined with a Corning 9780 glass filter about 2.5 mm thick.

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Table 2

Desired T Number	Value of θ = Cosec^{-1} ($2 \times T$ number), Degrees	Diameter of Aperture = 100 tan θ, mm
0.5	90	∞
0.71	45	100
1.00	30	57.74
1.41	20.708	37.80
2.00	14.478	25.82
2.83	10.183	17.96
4.00	7.181	12.60
5.66	5.072	8.88
8.00	3.583	6.26
11.31	2.533	4.42
16.00	1.791	3.12
22.63	1.266	2.21
32.00	0.895	1.56

telephotometer, or a small hole in an opaque screen can be moved around in front of the source, and any consequent variations in photocell reading noted.) The source conveniently may be a sheet of ground glass covering a hole in a white-lined box containing several lamps mounted around the hole and shielded so that no direct light from the lamps falls on the ground glass itself.

13.3.7 The photocell receiver conveniently may be of the phototube type with a simple direct-current amplifier.* Care must be taken to ensure that the phototube sensitivity and the line voltage do not change between making readings on the open aperture and on the lens itself; to guard against this, some convenient turret arrangement is desirable, with the lens on one side and the open aperture on the other so that the two may be interchanged and compared immediately with each other by merely turning the turret.

13.3.8 To measure the corner-to-center illumination ratio, the lens is set in position and the 3-mm hole and the photocell are displaced laterally by the desired amount. The photocell reading is noted at axial and corner positions, and the corresponding light ratio found from a calibration curve of the photocell meter.

* Suitable systems are the "Electronic Photometer" model 500 (Photovolt Corporation, 95 Madison Ave., New York, N. Y.), and the "Magnephot" (W. M. Welch Scientific Co., 1515 Sedgwick St., Chicago, Ill.). It is felt that a barrier-layer cell, although desirable for reasons of simplicity, has insufficient sensitivity for accurate determinations of the smaller apertures unless a galvanometer of exceptionally high sensitivity is employed.

13.4 Collimated Source Method of Lens Calibration

13.4.1 This method has been described by Daily [11] and Townsley,[14] the underlying theory being embodied in Section 5 above. Light from a small source (a 5-mm hole covered with opal glass and strongly illuminated from behind) is collimated by a simple lens, or an achromat if preferred, of about 15 inches focal length and 2 inches aperture. This gives a collimated beam which will be focused by the test lens to form a small disk of light in its focal plane. This circle of light will be less than the prescribed limit of 3-mm diameter for all lenses under 9 inches in focal length. Uniformity of the collimated beam can be checked by moving a small hole in an opaque screen across the beam, and any variations in the photocell reading noted.

13.4.2 For the comparison unit, an open aperture is used of diameter equal to the *focal length* of the lens divided by the desired *T* number. This aperture is first mounted in front of an integrating sphere with the usual photocell detector, and the light from the collimator is allowed to enter the aperture. The aperture plate is now replaced by the lens, the iris diaphragm is closed down to give the same photocell reading, and the *T*-stop number is engraved on the iris ring. The intermediate thirds of stops can be added by using 0.1 or 0.2 density filters, as described in Section 13.3.3.

13.4.3 To guard against drift and line-voltage variations which might occur between the readings on the comparison aperture and on the lens, it is convenient to leave the known standard aperture in place in front of the sphere, and to insert the lens into the beam in such a position that the little image of the source falls wholly within the standard aperture. The meter reading should then remain the same no matter whether the lens is in or out of the beam. A second plate with a 3-mm aperture should be placed over the compari-

son aperture while the lens is in place to stop any stray light which may be reflected from the interior of the lens.

13.4.4 It should be noted particularly that if this method is used, the focal length of the lens must be measured separately, and a suitable set of open apertures constructed for use with it. However, by suitable devices, one single set of fixed apertures may be used for all lenses, as described by Townsley.[14]

13.4.5 It should also be noted that this procedure measures f number as the ratio of f/D, and the measurement is thus influenced by the state of correction of the lens in regard to spherical aberration and sine condition.

13.4.6 The corner-to-center ratio at any desired aperture can be conveniently determined by simply rotating the lens through the desired field angle ϕ and comparing the photocell reading with its value for the lens axis. The light-flux ratio can then be read off a calibration curve for the photocell system, and converted to the desired corner-to-center illumination ratio by multiplying it by $\cos^3\phi$. (Note that this procedure will be correct only in the absence of distortion, but no motion-picture lens is likely to have enough distortion to cause any significant error.)

13.5 T-Stop Calibration at Finite Magnification

13.5.1 To use the *extended source* method (see Section 13.3), it is only necessary to mount the metal plate at the desired image distance from the lens instead of placing it in the focal plane. The open apertures used for comparison must be calculated to have an opening corresponding to the desired *Equivalent f* number multiplied by $(1 + m)$. This is because the illuminance given by the lens is really being compared with the *Effective f* number of the open hole, but the engraving must be done at each standard step of the *Equivalent f* number (see Section 12.2).

13.5.2 The *collimated source* method cannot be used to calibrate a lens at finite magnification.

References

General

1. A. C. Hardy, "The distribution of light in optical systems," J. Frank. Inst., vol. 208, pp. 773–791, Dec. 1929.

2. A. C. Hardy and F. Perrin, "Principles of Optics," McGraw-Hill Book Co., New York, 1932, p. 411.

3. L. C. Martin, "Applied Optics," vol. 2, Pitman, London, 1932, p. 210.

4. D. B. McRae, "The measurement of transmission and contrast in optical instruments," J. Opt. Soc. Am., vol. 33, pp. 229–243, Apr. 1943.

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5. G. W. Moffitt, "Determining photographic absorption of lenses," J. Opt. Soc. Am., vol. 4, pp. 83–90, May 1920.

6. J. Hrdlicka, "Measuring the effective illumination of photographic objectives," Jour. SMPE, vol. 14, pp. 531–553, May 1930.

7. D. B. Clark and G. Laube, "Twentieth Century camera and accessories," Jour. SMPE, vol. 36, pp. 50–64, Jan. 1941; also U.S. Patent 2,334,906 (filed Sept. 1940, issued Nov. 1943).

8. E. W. Silvertooth, "Stop calibration of photographic objectives," Jour. SMPE, vol. 39, pp. 119–122, Aug. 1942.

9. L. T. Sachtleben, "Method of calibrating lenses," U.S. Patent 2,419,421 (filed May 1944, issued April, 1947). (Note: This patent is held by RCA, which has expressed willingness to grant a paid-up license for a nominal fee. See Jour. SMPTE, vol. 56, pp. 691–692, June 1951.)

10. E. Berlant, "A system of lens stop calibration by transmission," Jour. SMPE, vol. 46, pp. 17–25, Jan. 1946.

11. C. R. Daily, "A lens calibrating system," Jour. SMPE, vol. 46, pp. 343–356, May 1946.

12. A. E. Murray, "The photometric calibration of lens apertures," Jour. SMPE, vol. 47, pp. 142–151, Aug. 1946.

13. I. C. Gardner, "Compensation of the aperture ratio markings of a photographic lens for absorption, reflection, and vignetting losses," Jour. SMPE, vol. 49, pp. 96–110, Aug. 1947; also J. Res. Nat. Bur. Stand., vol. 38, pp. 643–650, June 1947 (Research Paper RP 1803).

14. M. G. Townsley, "An instrument for photometric calibration of lens iris scales," Jour. SMPE, vol. 49, pp. 111–122, Aug. 1947.

15. F. G. Back, "A simplified method for the precision calibration of effective f stops," Jour. SMPE, vol. 49, pp. 122–130, Aug. 1947.

16. F. E. Washer, "Errors in calibrations of the f numbers," Jour. SMPE, vol. 51, pp. 242–260, Sept. 1948; also J. Res. Nat. Bur. Stand., vol. 41, pp. 301–313, Oct. 1948 (Research Paper RP 1927).

17. A. E. Murray, "Diffuse and collimated T-numbers," Jour. SMPTE, vol. 56, pp. 79–85, Jan. 1951.

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75th Convention

Members will soon be receiving the "First and Final" announcement of the Spring Convention. As was predicted, features of the Advance Program have been combined with the customary folded postcard and members thus have advance program information and hotel rates in one package. Applications for reservations, which should be sure to mention the SMPTE, or the reservation cards enclosed with the announcements, should be mailed without delay to the Front Office Manager, Hotel Statler, Washington, D.C. Rates are:

Single	\$ 8.00 to \$11.00
Double	11.00 to 15.00
Twin	14.50 to 19.50
Suites (for one or two)	29.50 to 37.00

The program has fully materialized along the substantial and broad outlines given in the three previous *Journals* — twelve sessions with fifty technical papers, from Monday noon to Friday night, May 3–7, at the Hotel Statler in Washington, D.C.

2d Int'l Symposium on High-Speed Photography

In October 1953 the first international conference in this field was held in Washington under the sponsorship of the SMPTE, with John H. Waddell as Symposium Chairman. The second symposium, which is being arranged by the Association Française des Ingénieurs et Techniciens du Cinéma, with the co-operation of a number of other European film associations, will take place in Paris September 22–28, 1954.

The organizing committee consists of Lucien Bull (Chairman), director of the Marey Institute, P. Libessart, H. Schardin, P. Fayolle, J. Vivié, P. Naslin and delegates from participating countries. Applications or enquiries concerning the symposium should be addressed to the Secretary of the Organizing Committee, P. Naslin, Laboratoire Central de l'Armement, Fort de Montrouge, Arceuil (Seine), France.

There will be papers on the optical, mechanical, electrical and electronic techniques and instruments in use in high-speed photography, and also on the applications of these techniques to the study of rapid events in the various scientific and technical fields. The three official languages of the symposium will be French, English and German.

Fees will be 1000 francs for authors of papers and 2000 francs for others attending. Within the limits of the available space there will be an opportunity to exhibit equipment, subject to the payment of a 20,000 franc fee per exhibit (\$1.00 equals 350 francs).

1954 Membership Directory — New Members

There is still time: Copy for the new Directory will be assembled at the end of this month. Three-fourths of the membership have returned the envelope and clipping sent two months ago with the membership dues invoices. Prompt replies are now in order, to be sure that listings are safely and properly in the new Directory.

New Members as a *Journal* column feature is being discontinued, for economy's sake, at least until the new Directory is issued.

SMPTE Officers and Committees: The roster of Society Officers and the Committee Chairmen and Members were published in the April 1953 *Journal*. A new roster is being prepared for the April 1954 *Journal*.

Section and Subsection Meetings

A meeting of the **Southwest Subsection** was held on November 20, 1953, at the Continental National Bank auditorium, Fort Worth, Texas. Guest speakers were George H. Brown, Director, Systems Research Laboratory, Princeton, N.J., and Robert E. Shelby, Director, Color TV Systems and Development, NBC New York, who discussed "Compatible Color Television and Its Relationship to the Broadcaster." Their discussion covered the NTSC compatible color television signal in terms of brightness signal combined with a color subcarrier which conveys hue and saturation information, and reviewed a number of the factors which influenced the choice of the color subcarrier frequency as well as some which influenced compatibility. Some transmitter requirements and related measuring equipment and methods were also described. Attendance was over 80, including some IRE members as guests. *W. W. Gilreath*, Secretary-Treasurer, Southwest Subsection, 3732 Stanford St., Dallas, Texas.

The **Pacific Coast Section** met on Tuesday evening, November 17, 1953, at Republic Studios in the San Fernando Valley. The program included a description and tour of the new Republic sound stage units, a screening of selections from a recent Republic wide-screen production, and a discussion of stereophonic sound by one of the top experts in the field.

Members were particularly impressed by the new television film production sound stages and the excellent technical discussion by Dan Bloomberg concerning their design and use. The color quality of a reel of daily rushes from the current production, *Johnny Guitar*, starring Joan Crawford and processed by Consolidated Film Industries, was also most impressive.

Following the opening film, William B. Snow discussed "Stereophonic and Pseudo-Stereophonic Sound in Motion-Picture Production," including an explanation of the use of such clues as intensity, quality and arrival time in creating the stereophonic illusion. Factors which aid in pickup were shown to cause complications in the listening room. Particular emphasis was given to the relationship between true stereophonic pickup and the pseudo-stereophonic methods employing electrical controls during re-recording to produce sound movement.

Approximately 450 persons attended the meeting. The Pacific Coast Section is very grateful to Mr. Bloomberg and his staff for their excellent cooperation in making the many arrangements necessary for handling a meeting of this size.—*Philip G. Caldwell*, Secretary-Treasurer, Pacific Coast Section, ABC Television Center, Hollywood 27, Calif.

The January 5th meeting of the **Pacific Coast Section,** held at the NBC Television Studios, Burbank, was an unusually interesting and popular program—an operating demonstration of color television, including the new NBC Mobile Color TV Unit brought to Southern California for the color telecast of the New Year's Day Rose Parade.

The meeting was conducted informally with a demonstration running continuously from 2:00 to 4:30 p.m., and during this time the audience was free to visit the exterior pickup location where two color cameras were in use, the mobile pickup unit and a stage where four color receivers were in operation. Attendance was about 600, and response to the picture quality and color was enthusiastic.

This very successful program was made available to the Section through the courtesy of O. B. Hanson, Vice-President and Chief Engineer of NBC New York, and A. H. Saxton, Manager, Technical Network Operations, NBC Hollywood.—*E. W. Templin*, Secretary-Treasurer, Pacific Coast Section, c/o Westrex Corp., 6601 Romaine St., Hollywood 38, Calif.

The **Central Section** held a meeting at the Western Society of Engineers building on January 21. The large auditorium was used and some 80 members were in attendance. "Basic Chemistry of Photography," a paper presented by Thomas T. Hill, Chief Photographic Chemist, Ringwood Chemical Corp., outlined the role of chemistry and of chemicals in the photographic process from the standpoint of motion-picture engineering. After describing the

physical properties and constitution of motion-picture film, Mr. Hill discussed some of the controls which are possible with chemicals and the precautions necessary to avoid difficulty with developer and fixing solutions.

A second paper, "A History of Color Film Reproduction," was given by Ray Balousek, President of Grossman-Knowling, Detroit. The first part of this paper was concerned with the historical highlights of color cinematography from the first two-color Kodachrome and two-color Technicolor imbibition process up to the present 35mm negative-positive color films. The second part discussed present-day problems in regard to color slide film animation, particularly with negative-positive films. Illustrative slides were shown on all phases of these processes and a slide film reviewed some of the historical color procedures.—*K. M. Mason*, Secretary-Treasurer, Central Section, 137 North Wabash Ave., Chicago.

Obituaries

George K. Spoor, one of the pioneers of the motion-picture industry, died November 24, 1953. He was 81 years old.

He was born in Highland Park, Ill., left school at 16 and went to work for the North Western Railroad. At the age of 23 he met the inventor of the magniscope, a precursor of the moving picture machine. George Spoor invested in it and in 1897 he and Gilbert M. (Broncho Billy) Anderson founded the Essanay Film Company in Chicago. Two years later he bought the rights to the kinedrome, a moving picture projector and during the succeeding years, until the lot closed in 1916, the Essanay Company was the proving ground for many of the greatest stars of the silent films.

Also prominent as an inventor of motion picture equipment, Spoor worked for years on the three-dimensional process known as Natural Vision. A description of his achievements, after 7 years of experimenting, was published in the *New York Times* of August 21, 1923. In 1925 he showed 3-D films to an invited gathering in Chicago and comments such as "Clear as real life!" "This puts ordinary movies in a class with lantern slides!" and "Just like looking through a plate glass window!" flew thick and fast. However a 3-D film entitled *Danger Nights*, which was offered for public consumption in 1930, proved an economic failure.

Hyman Goldin died on January 6, 1954, in Toronto, He was 48 years old.

Mr. Goldin received his early education in Montreal and graduated from the University of Toronto. Until 1946 he was with Dominion Sound Equipments (Canadian Westrex), from 1946 to 1951 he was Chief Engineer of Gaumont-Kalee, Toronto, and since 1951 Chief Engineer of Perkins Electric Co., Toronto. During the war he was loaned to the Canadian Government and assisted in perfecting the intercommunications system used in Lancaster bombers. For the past three years he had been working as a consulting engineer on acoustic problems. He served on various committees of the SMPTE and in Canada was an active member of the Canadian Standards Association Committee Z7.1 on Motion Picture Photography.

Book Reviews

Television Broadcasting

By Howard A. Chinn. Published (1953) by McGraw-Hill, 330 W. 42 St., New York 36, N.Y. i-ix + 690 pp. + 10 pp. index. 346 illus. 6 × 9 in. Price $10.00.

This book is intended for the television broadcast operator. It should be particularly timely for the many radio engineers who face television operations for the first time, in the hundreds of new stations being built. It is a single complete reference volume covering the practical problems of television broadcast station construction and operation.

Mr. Chinn writes with authority befitting his stature and vast experience in the broadcast field. Those who share an acquaintance with Mr. Chinn can appreciate the patience and diligence which have gone into the book's preparation.

The book is readable. It is not so theoretical as to be discouraging, and yet the meat is there. For example, the synchronizing generator, which is the most difficult piece of equipment for the uninitiated to comprehend, is adequately explained. Sufficient information is given for a basic

understanding of the gross differences among equipment types, so that the new engineer can choose. The presentation is exactly at the proper level for the intended audience.

The content runs the complete range from television fundamentals to color television. Considerable space is devoted to the image orthicon tube and the camera in which it is used. Field pickups and the appropriate equipment are discussed in some detail. Studio equipment, lighting, projectors and film problems are well treated, as are the TV transmitter, antennas and feed lines. Even building planning is presented, with many helpful hints for the new broadcaster. The chapter on color television covers the field-sequential system which was the law of the land at the time of the manuscript, but which has since been replaced by the compatible system of NTSC. However, there are many applications of the field-sequential system which well justify the treatment.

All through the chapters runs the theme of achieving a professional level of operations. It is clearly demonstrated that care with small matters will automatically resolve system difficulties and result in an operation of which the newcomer to television can be proud.

This volume deserves wide distribution in the radio and television field as a thoroughly practical operating handbook. It proves that television, while an electronic miracle, is still a creature of ordinary man; and that ordinary man can understand and control it. This book is wholeheartedly recommended to the membership of the Society for interesting reading and conscientious study. In preparing it, Mr. Chinn has rendered a valuable service to the television broadcast industry.—*A. E. Hungerford, Jr.*, General Precision Laboratory Inc., Pleasantville, N.Y.

Thermionic Vacuum Tubes and Their Applications, 6th ed.

By W. H. Aldous and Edward Appleton. Published (1952) by John Wiley & Sons, Inc., 440 Fourth Ave., New York 16, N.Y. 151 pp. + 98 illus. 4 × 6½ in. $2.00.

This little book treats conventional vacuum tubes, including magnetrons, klystrons and traveling wave tubes as to internal electron action and the applications thereof as amplifiers, rectifiers, frequency changers, oscillators, reactance tubes and relaxation devices.

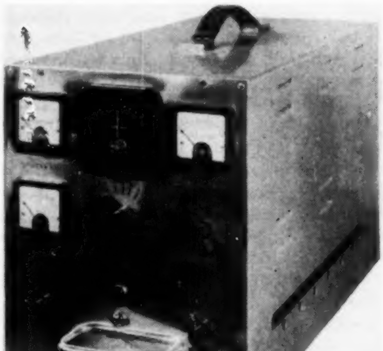
Numerous equations are given in explanation of the phenomena to the physicist and for purposes of design for the engineer. A terse approach has been taken and more factual information has been provided than would be surmised from the size of the volume.

The book is British: W. H. Aldous being on the Research Staff of the M. O. Valve Co. at the G.E.C. Research Laboratories, Wembley, England; and Sir Edward Appleton being Principal and Vice-Chancellor of Edinburgh University.

Over a hundred references are listed for further reading.—*Harry R. Lubcke*, Reg. Patent Agent, 2443 Creston Way, Hollywood 28, Calif.

New Products

Further information about these items can be obtained direct from the addresses given. As in the case of technical papers, the Society is not responsible for manufacturers' statements, and publication of these items does not constitute endorsement of the products.



The Gaumont-Kalee Flutter Meter is designed to measure small frequency variations of a given carrier frequency. If the meter is provided with

a signal of the correct frequency and of suitable amplitude, variations from constant speed of the recording and/or reproducing machine can be measured. The instrument operates at a nominal carrier frequency of 3000 cycles/sec, but will tolerate up to 5% variation in mean carrier frequency, thus enabling measurements to be made on machines that are running off speed, or using film of disks whose recorded 3000-cycle tone is inaccurate.

The meter consists of a narrow-band amplifier, a limiter, a discriminator and detector, and a metering system, the whole unit being self-contained with its own power supplies. The input amplifier is tuned to 3000 cycles/sec and has a bandwidth of 1000 cycles/sec. It is provided with an input control for adjusting signal level. An amplitude limiter, which eliminates effects caused by signal level variations, is followed by a power amplifier which drives a discriminator operating at a mean frequency of 3 kc. The discriminator may be tuned from 2850 to 3150 cycles/sec to accommodate variations in mean carrier frequency. The error in the input frequency expressed as a percentage of speed is indicated on a scale. The input signal level at the discriminator, which is set up on a meter by means of a control in the limiter circuit, is maintained constant by the limiter.

The Gaumont-Kalee Flutter Meter is distributed in the U.S. by S.O.S. Cinema Supply Corp., 602 West 52d St., New York 19.

Employment Service

These notices are published for the service of the membership and the field. They are inserted for three months, at no charge to the member. The Society's address cannot be used for replies.

Positions Wanted

Motion-Picture Television Technician: 10 yr intensive skill and know-how related to 16-35mm cinematography, animation, recording (optical, tape, disk), editing, laboratory processing practice (black-and-white, color); also kinescope recording techniques; self-reliant; inventive; relocate if required; write: CMC, Technical Associates, 60 East 42d St., New York 17, N.Y.

Motion-Picture Cameraman: Retiring from Naval Service. 15 yr experience in camera operation, printing, processing, adm. and supervision of production crews. Desires position in TV, educational or industrial field, inaugurating a motion-picture program. Available after May 1954. Prefer West Coast. Write: W. W. Collier, 422 W. Jackson Ave., Warrington, Fla.

Positions Available

Wanted: Sound Engineer for New York film production studio, operation and maintenance on optical and magnetic sound equipment; electronics background essential. Send résumé to R. Sherman, 858 West End Ave., New York, N.Y.

Technical Photographer, age 27 to 38, for senior position with large California industrial research organization. Should be conversant with contemporary techniques for recording data; acquainted with microscopy, graphic arts and color processes. Job involves application of photographic techniques as experimental tool in research projects. Administrative experience helpful. Excellent career opportunity for an ingenious and inventive person. Retirement pension and other benefit plans. Application held in strict confidence. Write giving personal data, education and experience to Henry Helbig and Associates, Placement Consultants, Examiner Bldg., 3d and Market Sts., San Francisco 3, Calif.

Sound Engineer: Complete responsibility for sound control, including printing, processing, maintenance of standards, etc. Tri Art Color Corp., 245 West 55th St., New York 19, N.Y.

Motion-Picture Supervisor, GS-8: Duties as Chief of Motion Picture Section to include all phases of aeromedical research cinematography. Experience in planning, directing, lighting, color control, recording in single or double-system sound. Laboratory work requires experience with sensitometric control equipment, contact printers, automatic processors, Moviola, sound synchronization equipment, titlers, etc. For detailed information write: Photography Officer, USAF School of Aviation Medicine, Randolph Field, Texas.

Motion-Picture Sound Transmission Installer and Repairer, for the Signal Corps Pictorial Center, Long Island City, N. Y.—one at \$2.59/-hr; one at \$2.29/hr (40-hr week). Applicants for \$2.29/hr position must have had 4½ yr progressively responsible experience in the construction, installation and maintenance of electronic equipment, of which at least 1½ yr must have been in the specialized field of motion-picture film, disk or magnetic sound recording or reproducing equipment. Applicants for \$2.59/hr position must have had at least 5 yr responsible experience in the design, development and installation of electronic equipment, of which at least 2 yr must have been in the specialized field of motion-picture film, disk or magnetic sound recording or reproducing equipment. Must be familiar with filter design and transmission testing, involving the use of a wide variety of testing and measuring

devices. Each year of study successfully completed in a residence school above high school level in electrical, electronic or radio engineering, may be substituted for the general, but not the specialized experience indicated above, at the rate of one scholastic year for each 9 mo. of experience. All applicants must be familiar with Western Electric and RCA systems. Obtain Form SF 57 at any first class Post Office or Government Agency; forward or bring completed form to Civilian Personnel Division, Signal Corps Pictorial Center, 35-11 35th Ave., Long Island City, N.Y.

Photographic Engineer: Wanted for design and development work involving application of film and associated equipment to monochrome and color TV systems. Prerequisites are BS or equivalent, and experience in at least one of the following motion-picture fields: (a) TV film applications, (b) processing laboratory design and operation, (c) camera and projector design or (d) sensitometry and densitometry. Please send résumé to Personnel Dept., CBS Television, 485 Madison Ave., New York 22, N.Y.

Sales Management Engineer: To head division manufacturing single optical track stereo sound system. Already adopted by major studio. Position requires knowledge of theater sound systems here and abroad. Reply to: Fairchild, Rm. 4628, 30 Rockefeller Plaza, New York 20, N.Y.

Engineer: To direct engineering of flying-spot TV projector with millisecond pulldown mechanism. Mechanism already developed and working. Reply to: Fairchild, Rm. 4628, 30 Rockefeller Plaza, New York 20, N.Y.

Wanted — Consultant technician: Thorough knowledge of Houston continuous double-head printer, Houston developing machines, Bell & Howell printers and Debrie Matipo step printer. Must put machines in running order and train operating personnel. Usual per day rate and plane fare to Puerto Rico. Address replies to R. J. Faust, Chief, Cinema Section, Dept. of Education, Commonwealth of Puerto Rico, Division of Community Education, P. O. Box 432, San Juan, Puerto Rico.

Wanted — Engineer for N.Y. Film Processing Lab: Opportunity for experienced individual to direct maintenance and engineering of color/-B&W printing and processing equipment. Submit complete résumé (replies strictly confidential) to: Irwin Young, Du-Art Film Laboratories, Inc., 245 W. 55 St., New York 19, N.Y.

Permanent Position: Open for versatile 16mm cameraman familiar with all phases of industrial production. Write McLarty Picture Productions, 45 Stanley St., Buffalo 6, N.Y.

Meetings

National Electrical Manufacturers Assn., Mar. 8-11, Edgewater Beach Hotel, Chicago, Ill.

Radio Engineering Show and I.R.E. National Convention, Mar. 22-25, Hotel Waldorf Astoria, New York

Optical Society of America, Mar. 25-27, New York

The International Sound Track Recording Convention has been announced by the Association of Radioelectricians, 10 Ave. Pierre Larousse, Malakoff (Seine), France, to be held in Paris, April 5-10, 1954, on sound-track recording processes and their extension to other fields of application. Radio and television networks and the motion-picture industry will participate with technical papers, an exhibition of equipment, and tours of plants and technical centers. Problems of standardization will be discussed.

The Calvin Eighth Annual Workshop, Apr. 12-14, The Calvin Co., Kansas City, Mo.

International Symposium on Information Networks (information from Microwave Research Institute, Polytechnic Institute of Brooklyn, 55 Johnson St., Brooklyn 1, N.Y.), April 12-14, Engineering Societies' Building, New York

Society of Motion Picture and Television Engineers, Central Section, Spring Meeting, Apr. 15, The Calvin Co. Sound Stage, Kansas City, Mo.

75th Semiannual Convention of the SMPTE, May 3-7, Hotel Statler, Washington

American Institute of Electrical Engineers, Summer General Meeting, June 21-25, Los Angeles, Calif.

Acoustical Society of America, June 22-26, Hotel Statler, New York

Illuminating Engineering Society, National Technical Conference, Sept. 12-16, Chalfonte-Haddon Hall, Atlantic City, N.J.

Photographic Society of America, Annual Meeting, Oct. 5-9, Drake Hotel, Chicago, Ill.

American Institute of Electrical Engineers, Fall General Meeting, Oct. 11-15, Chicago, Ill.

76th Semiannual Convention of the SMPTE, Oct. 18-22, Ambassador Hotel, Los Angeles

77th Semiannual Convention of the SMPTE, Apr. 17-22, 1955 (next year), Drake Hotel, Chicago

The International Commission on Illumination is to hold its next international conference in Zürich, Switzerland, June 13-22, 1955 (*next year*). Offers of papers should be addressed to the Chairman of the Papers Committee (A. A. Brainerd), 1015 Chestnut St., Philadelphia 7. Manuscripts must be in the hands of the Central Bureau between Oct. 1 and Dec. 31, 1954.

78th Semiannual Convention of the SMPTE, Oct. 3-7, 1955 (next year), Lake Placid Club, Essex County, N.Y.

SUSTAINING MEMBERS

OF THE

SOCIETY OF MOTION PICTURE AND TELEVISION ENGINEERS

Alexander Film Co.
Altec Companies
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The Ballantyne Company
Bausch & Lomb Optical Co.
Bell & Howell Company
Bijou Amusement Company
Buensod-Stacey, Inc.
Burnett-Timken Research Laboratory
Century Projector Corporation
Cineffects, Inc.
Cinéma-Tirage L. Maurice
Geo. W. Colburn Laboratory, Inc.
Color Corporation of America
Consolidated Film Industries
DeLuxe Laboratories, Inc.
De Vry Corporation
E. I. du Pont de Nemours & Co., Inc.
Eastman Kodak Company
Max Factor, Inc.
Federal Manufacturing and Engineering Corp.
Fordel Film Laboratories
General Electric Company
General Precision Equipment Corp.

- Ampro Corporation
- Askania Regulator Company
- General Precision Laboratory, Incorporated
- The Hertner Electric Company
- International Projector Corporation
- J. E. McAuley Mfg. Co.
- National Theatre Supply
- The Strong Electric Company

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Guffanti Film Laboratories, Inc.
Hunt's Theatres
Hurley Screen Company, Inc.
Kollmorgen Optical Corporation
Lorraine Carbons
J. A. Maurer, Inc.
Mecca Film Laboratories, Inc.
Mitchell Camera Corporation
Mole-Richardson Co.
Motiograph, Inc.
Motion Picture Association of America, Inc.

- Allied Artists Productions, Inc.
- Columbia Pictures Corporation
- Loew's Inc.
- Paramount Pictures Corporation
- Republic Pictures Corp.
- RKO Radio Pictures, Inc.
- Twentieth Century-Fox Film Corp.
- Universal Pictures Company, Inc.
- Warner Bros. Pictures, Inc.

Movielab Film Laboratories, Inc.
National Carbon Company

- A Division of Union Carbide and Carbon Corporation

National Cine Equipment, Inc.
National Screen Service Corporation
National Theaters Amusement Co., Inc.
Neighborhood Theatre, Inc.
Neumade Products Corp.
Northwest Sound Service, Inc.
Polaroid Corporation
Producers Service Co.
Projection Optics Company, Inc.
Radiant Manufacturing Corporation
Radio Corporation of America, RCA Victor Division
Reid H. Ray Film Industries, Inc.
Raytone Screen Corp.
Reeves Sound Studios, Inc.
S.O.S. Cinema Supply Corp.
SRT Television Studios
Shelly Films Limited (Canada)
The Stancil-Hoffman Corporation
Technicolor Motion Picture Corporation
Titra Film Laboratories, Inc.
Wenzel Projector Company
Westinghouse Electric Corporation
Westrex Corporation
Wilding Picture Productions, Inc.
Wollensak Optical Company